The 37th International Geological Congress 2024

Lunar, Mars, and Asteroid Exploration for Space Resources

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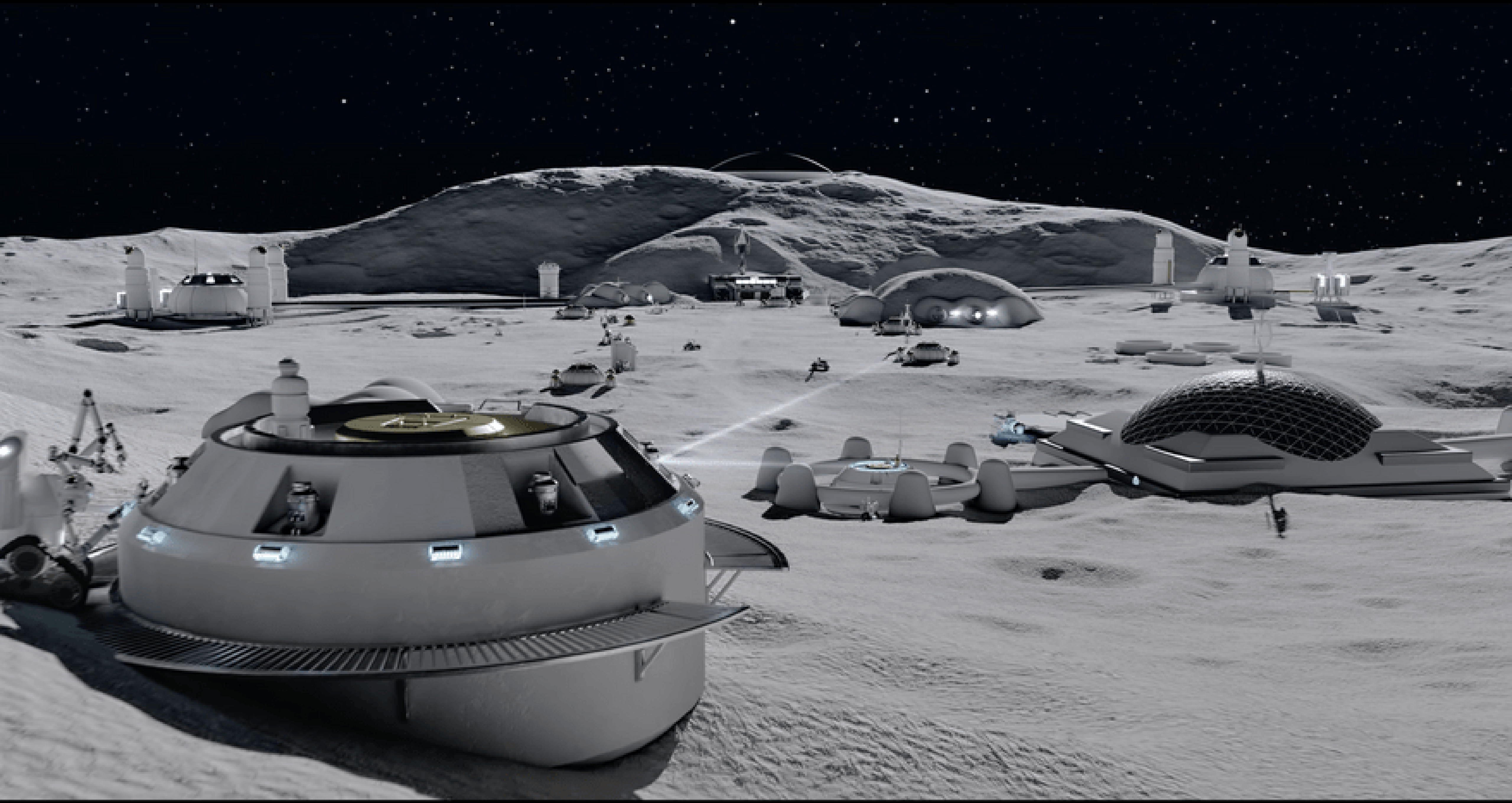


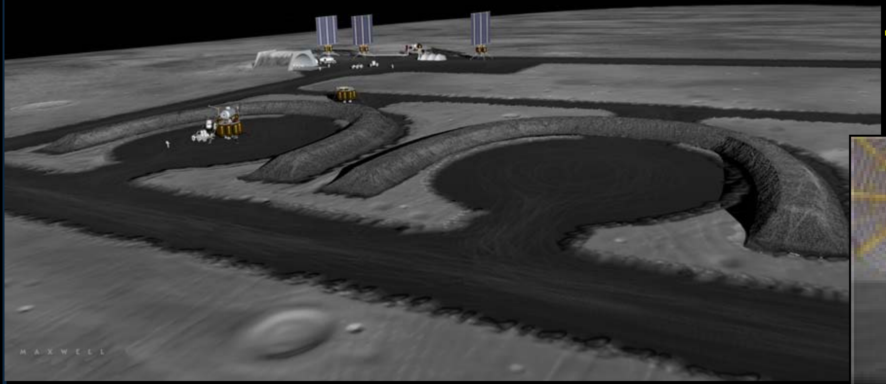
Credit: Lockheed Martin Destination Space: 2050 YouTube screenshot

All Images credit: NASA

Resource Prospecting – Looking for Resources

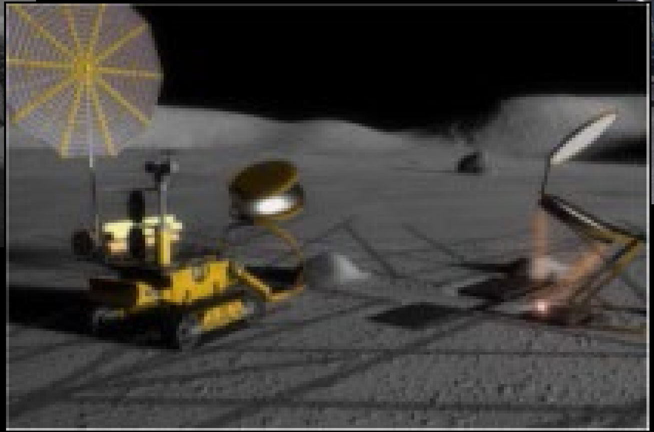
Excavation & Regolith Processing for H_2 & O_2 Production, Binders & Aggregates

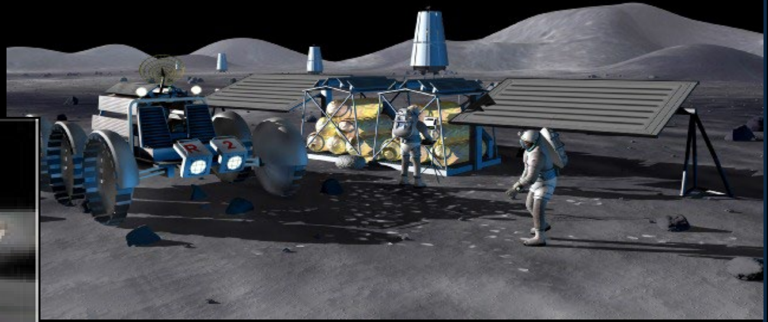
Propellant Processing with Lander & Pad Infrastructure



Habitat, Hangars, Dust Free Zones, Landing Pads, Berm, and Road Construction

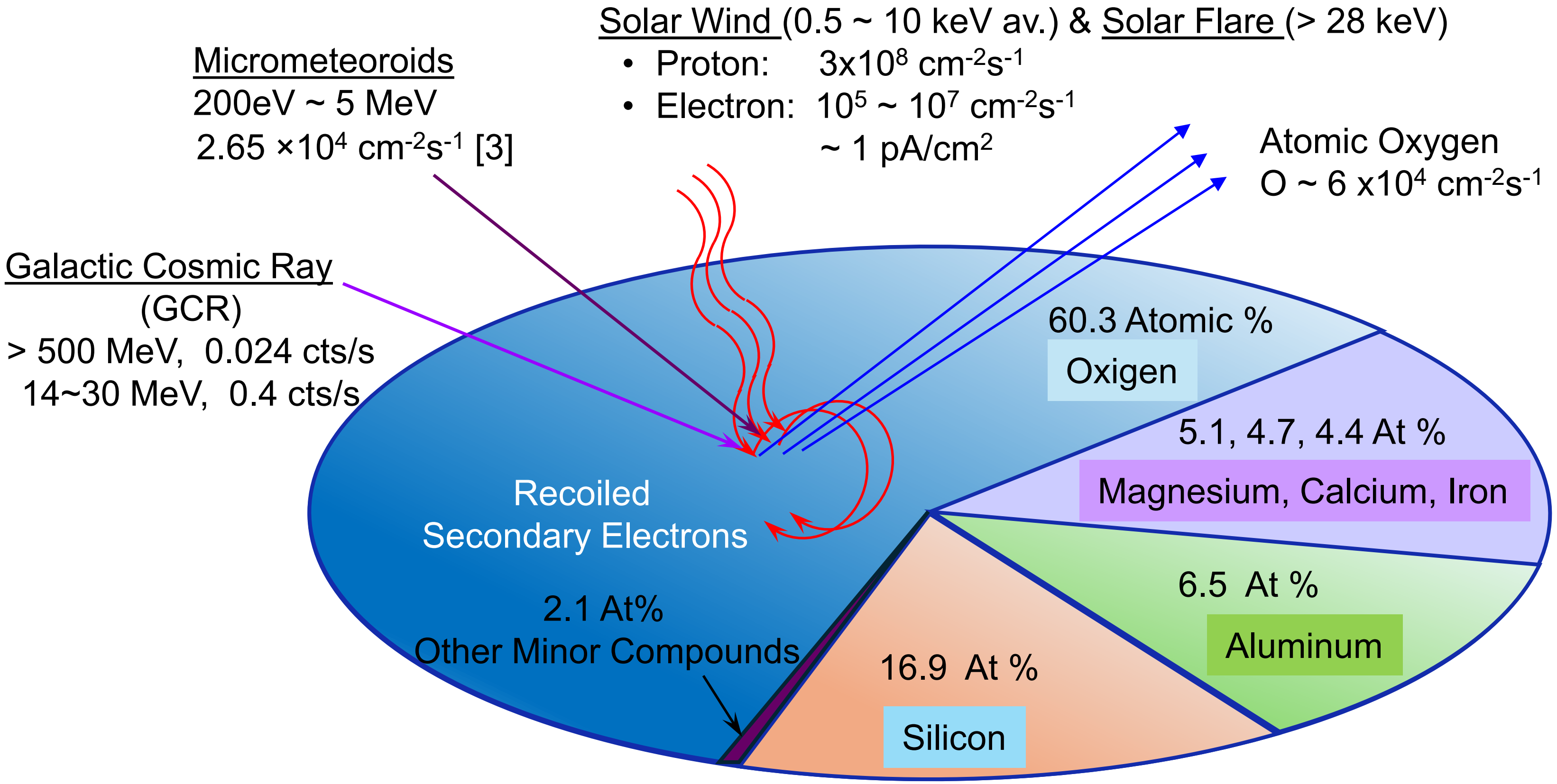
Thermal Energy Storage Construction





Construction of Consumables Depots for Crew & Power (O_2, H_2)

Lunar Dust Composition
- Elemental Analysis



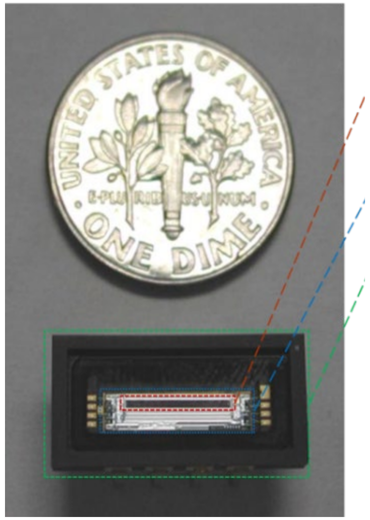
Composition Data:

Turkevich, A. L., "The Average Chemical Composition of the Lunar Surface", Proceedings of the Lunar Science Conference, Vol. 4, pp.1159-1168, 1973.

Probes for Survey and Assay
- Microspectrometer (MSM) -

Spectrometer technology:	Fresnel diffraction grating
Resolution:	< 5 nm with resolving power 100 lines
Targeted spectral range:	Addressable pixel
Bullet configuration:	Remotely deployable
Cost of MSM:	< $200 ea

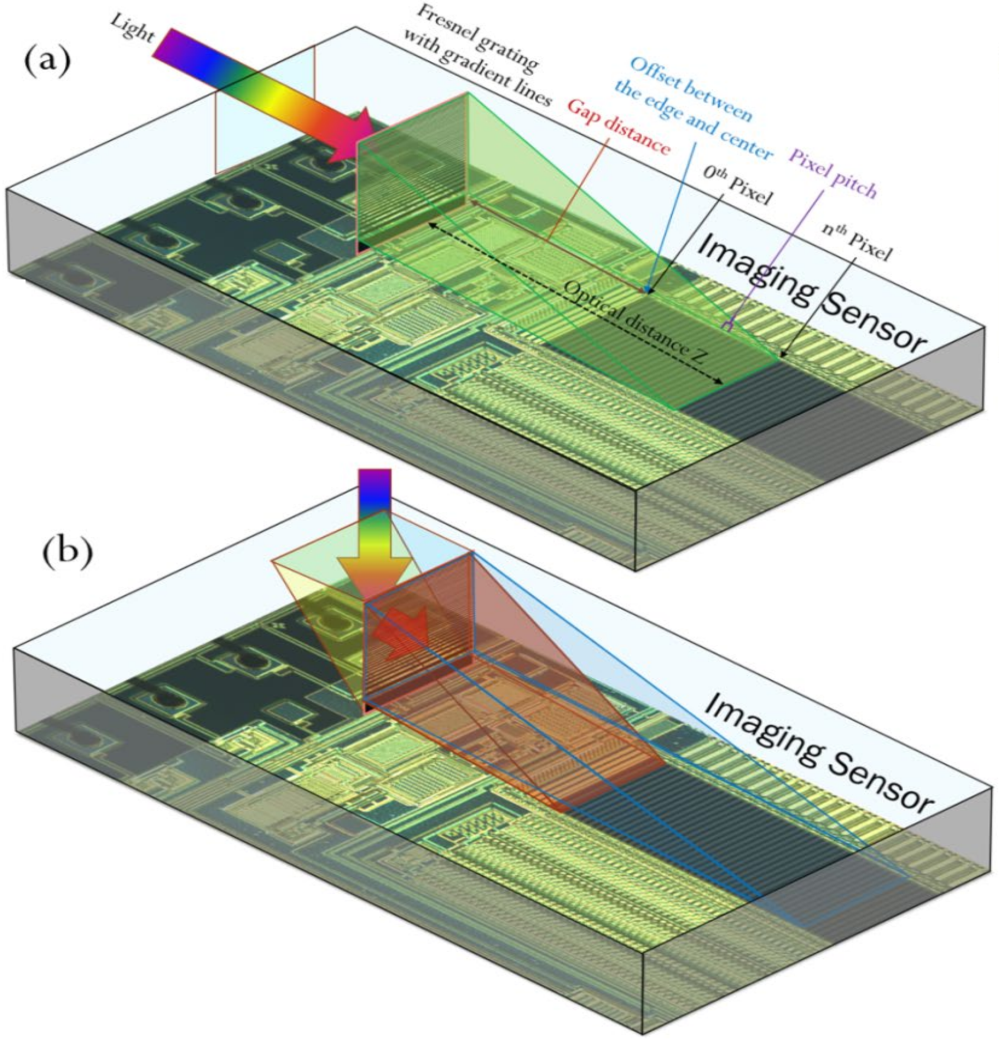
Spectrometer Chip

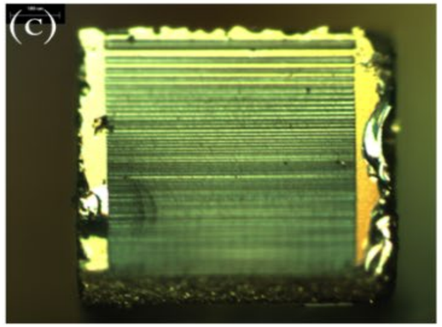


Active Area: 6.4 mm x 0.5 mm
(Spectrum Area)

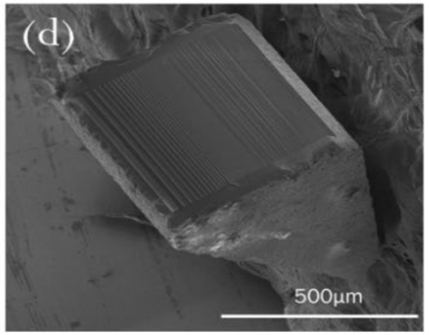
Die Size: 9.5 mm x 2.5 mm

Packaging: 15.8 mm x 7.87 mm



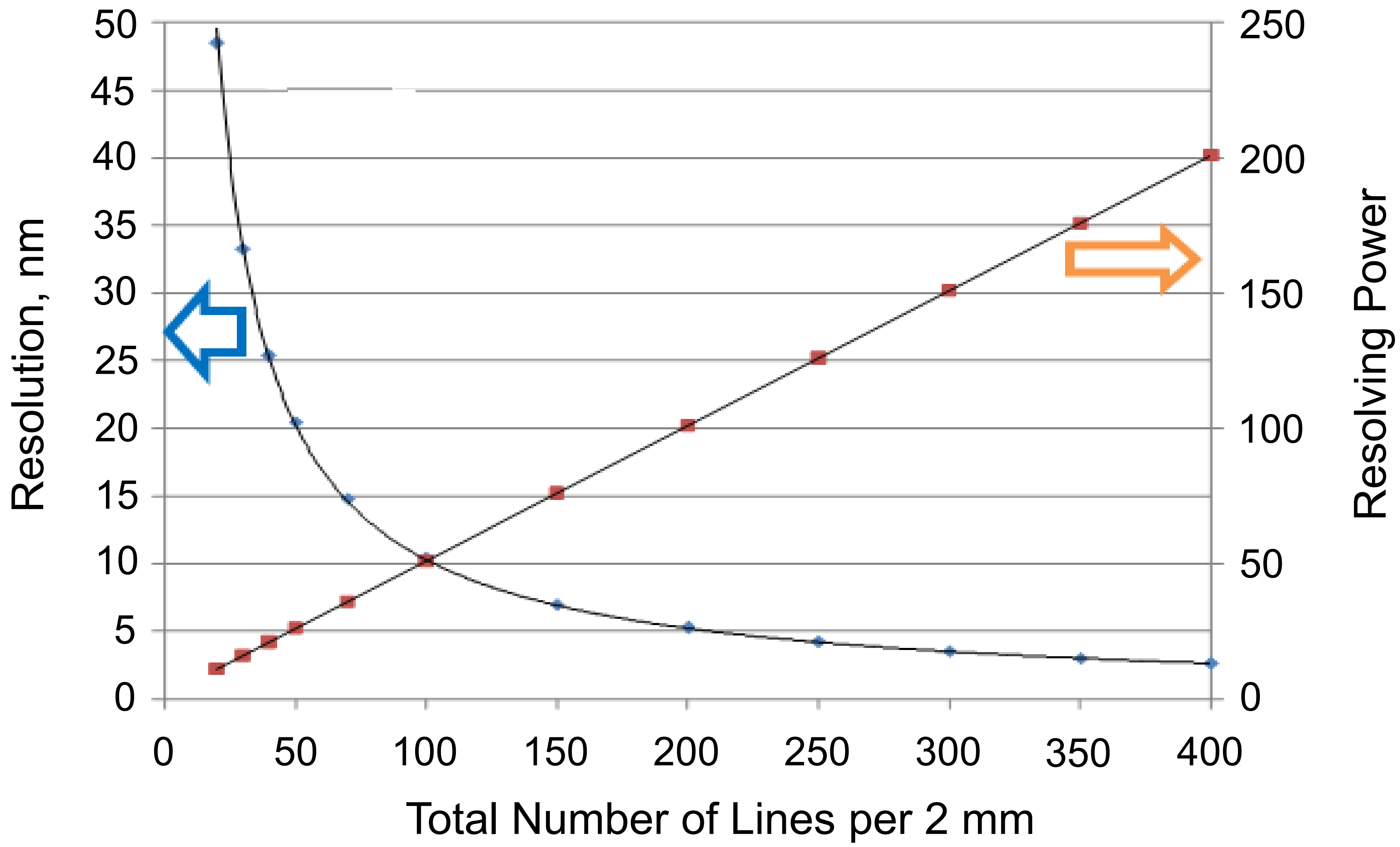


700 μm

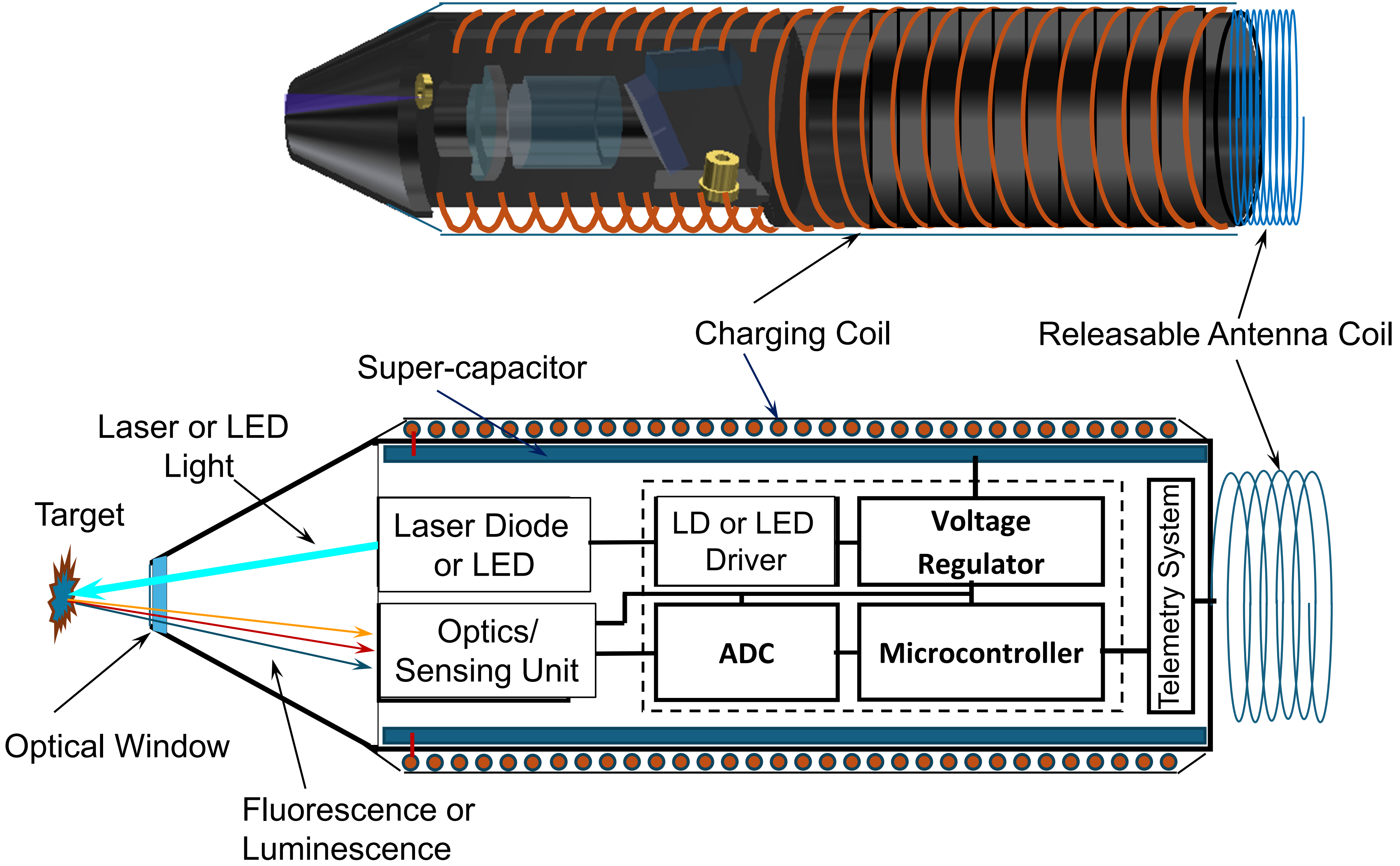


500 μm

Spectral Data & Resolution of Differential Line Fresnel Grating



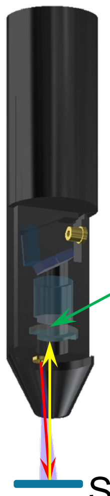
Bullet Micro-Spectrometer

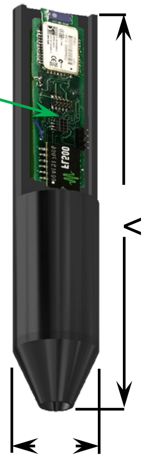


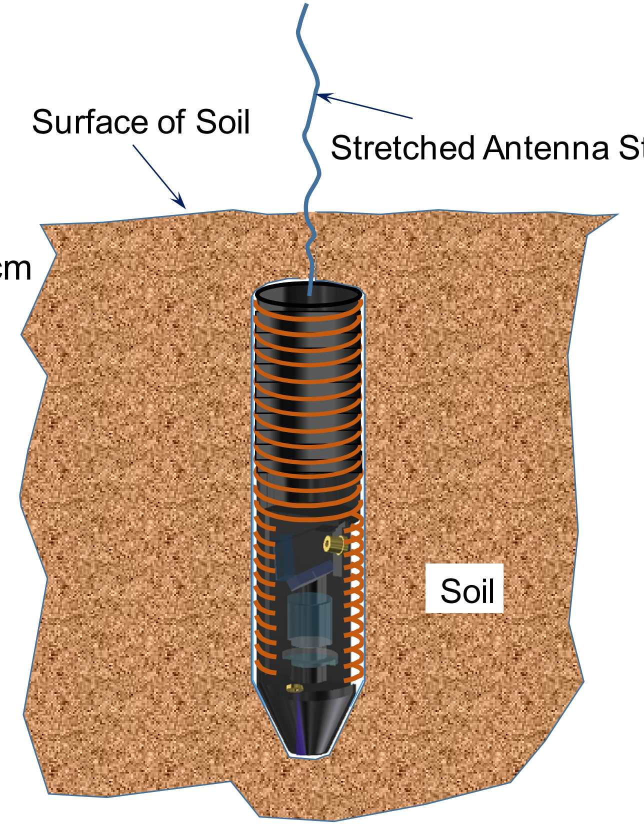
Bullet Micro-Spectrometer

Micro-Spectrometer

- Principle of Fresnel diffraction
- Light source: Deep or vacuum UV from burst-mode LED
- Pulse mode power feed from super-capacitor
- Bullet-like consumable micro-spectrometers (< $100)
- Shooting by compressed air gun

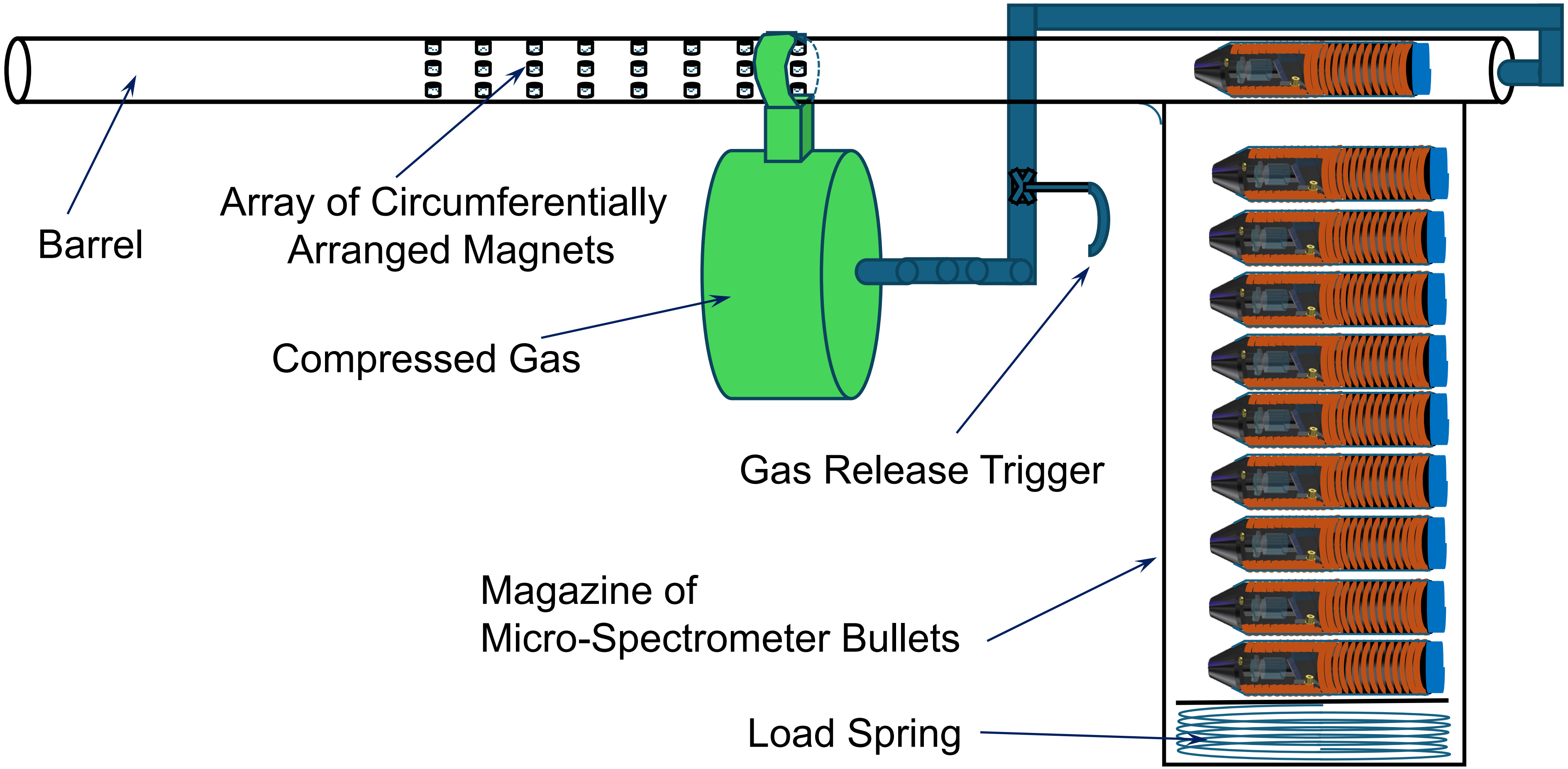




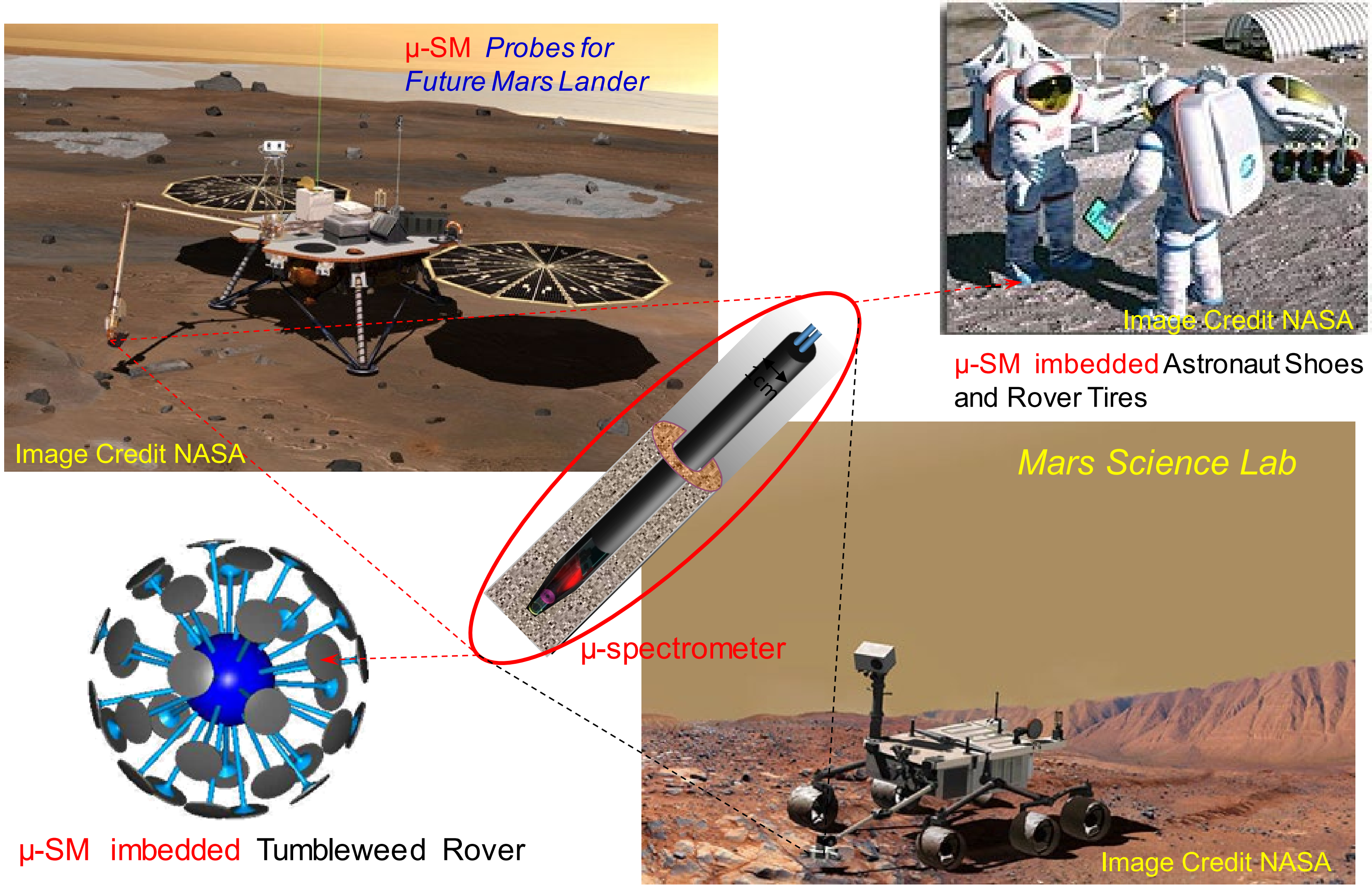


Langley invented micro-spectrometer meets NASA Roadmap 12 Science Instruments and Sensors.

Gas Gun for Bullet Micro-Spectrometer

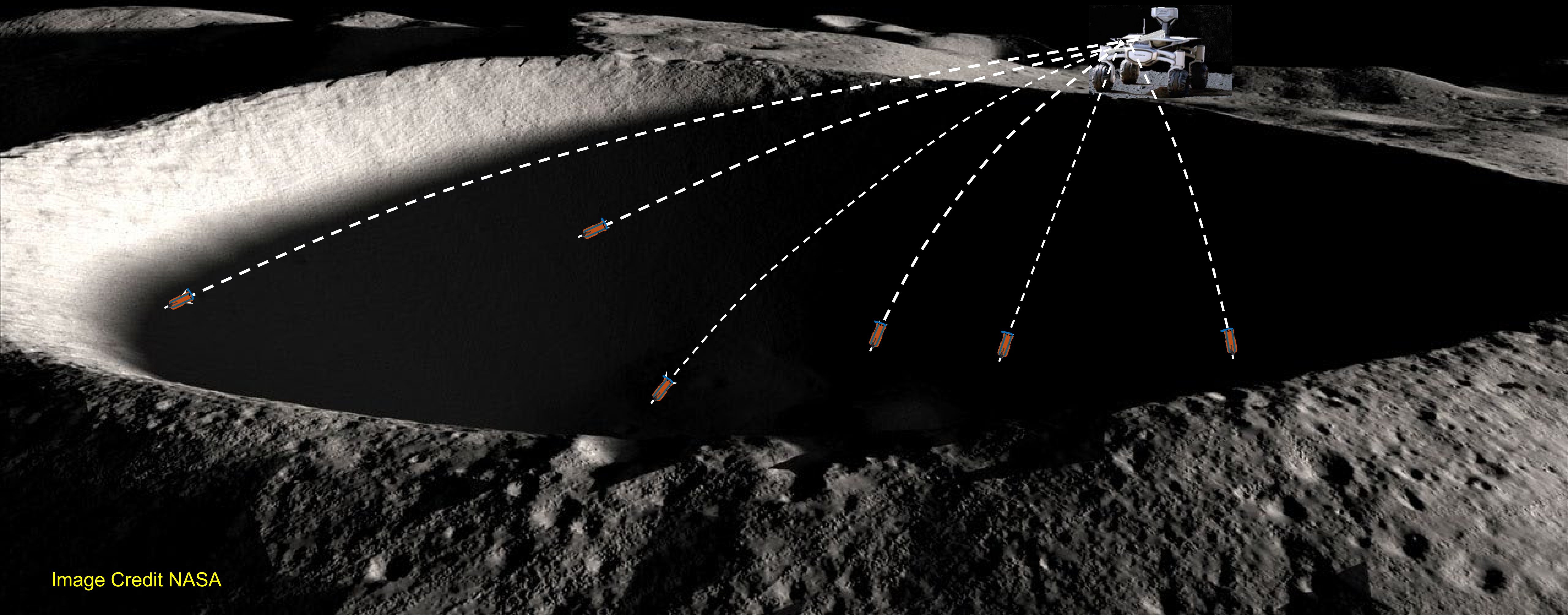


Micro-Spectrometer for Lunar & Mars Exploration



Lunar Soil Assay by Bullet Micro-Spectrometer

Penetration of Bullet Micro-Spectrometer into Steep Hillside and Bottom of Crater



Asteroid Soil Assay by Bullet Micro-Spectrometer

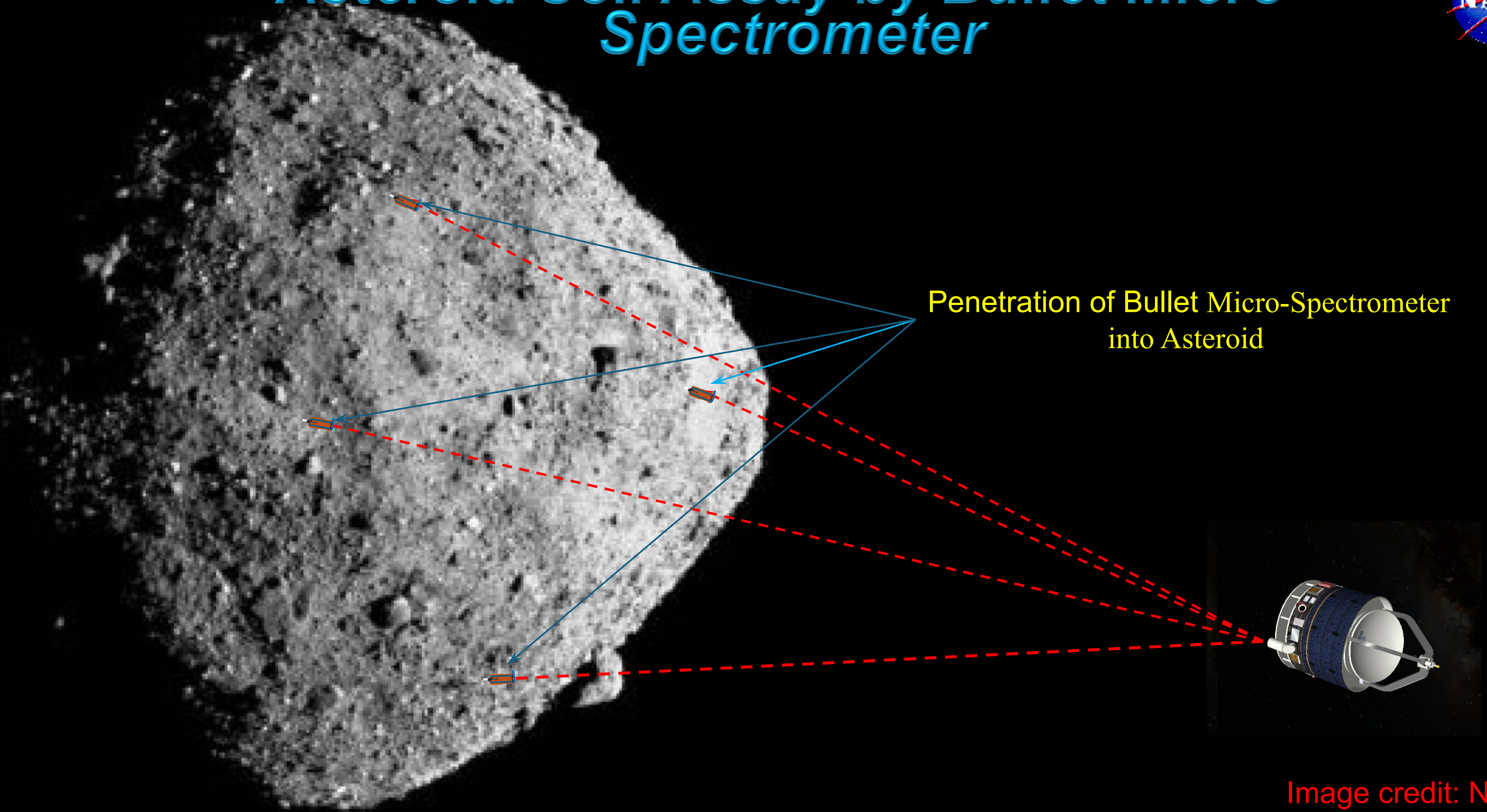


Image credit: NASA

Lunar Volatiles Collector (LVC)
- Bessel Tube (BT) -

Volatiles:

- Helium-3 in dangling bond on lunar surface: Assaying, collecting, and storing
- Oxygen (processed from ice-water or oxides)
- CO_2 on Mars for oxygen and propellant production
- Mechanical, chemical, or electrical processors for splitting oxides, H_2O, or CO_2, collecting, and storing

Volatile: Helium-3 Mining

Helium-3

Neutrons	1
Protons	2
Parent Isotopes	^{3}H (β-decay)
Isotope Mass	3.016 u
Half Life	stable
Spin	½+
Availability	0.000137% in Atm

Helium-3 in regolith

Dangling bond –	van der Waals
	Electrostatic
	Trapped

Resources

Earth Mantle	~ 10^{6} tons
Ocean Floor	4000 tons
Lunar Regolith	~ 10^{6} tons

Needs

U.S.A.	20 tons/yr ($60B worth)
Others together	80 tons/yr

Price:

$3B/ton

Rationale

Fusion reactions involving Helium-3			
Reactants		Products	Q
First Generation Fuels			
$^{2}_{1}H + ^{2}_{1}H$	→	$^{3}_{2}He + ^{1}_{0}n$	3.268 MeV
$^{2}_{1}H + ^{2}_{1}H$	→	$^{3}_{1}H + ^{1}_{1}p$	4.032 MeV
$^{2}_{1}H + ^{3}_{1}H$	→	$^{4}_{2}He + ^{1}_{0}n$	17.571 MeV
Second Generation Fuel			
$^{2}_{1}H + ^{3}_{2}He$	→	$^{4}_{2}He + ^{1}_{1}p$	18.354 MeV
Third Generation Fuel			
$^{3}_{2}He + ^{3}_{2}He$	→	$^{4}_{2}He + 2\,^{1}_{1}p$	12.86 MeV

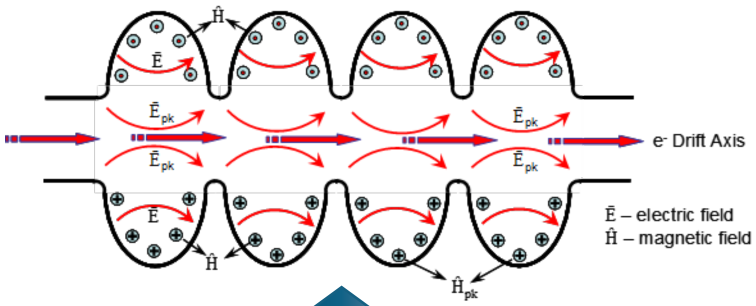
Aspiration

(Richard B. Bilder, Fordham International Law Journal, Vol. 33, Iss. 2, 2009)

U.S.A.	One of the justifiable space expeditions (2015)
China	Officially stated goal of Chinese lunar exploration program
Russia	Helium-3 mining plan by Russia's RKK Energia by 2020
Japan	???
India	Officially, but no details

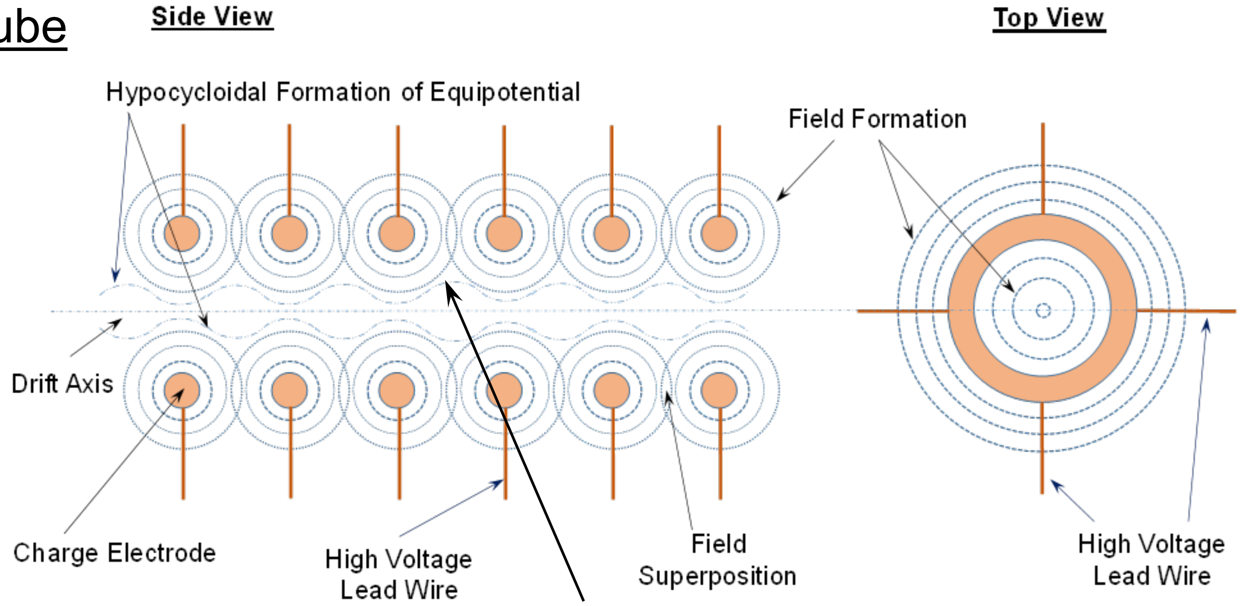
Bessel Tube (BT) Concept for Volatile Collection

Electron Accelerating Cavity

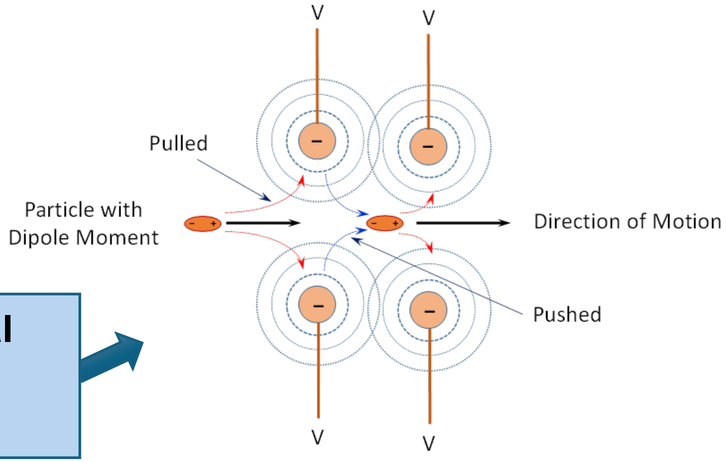


Cylindrical harmonic generator in a hypocycloidal mode used for accelerating electrons in electron Accelerator laboratory.

Bessel Tube

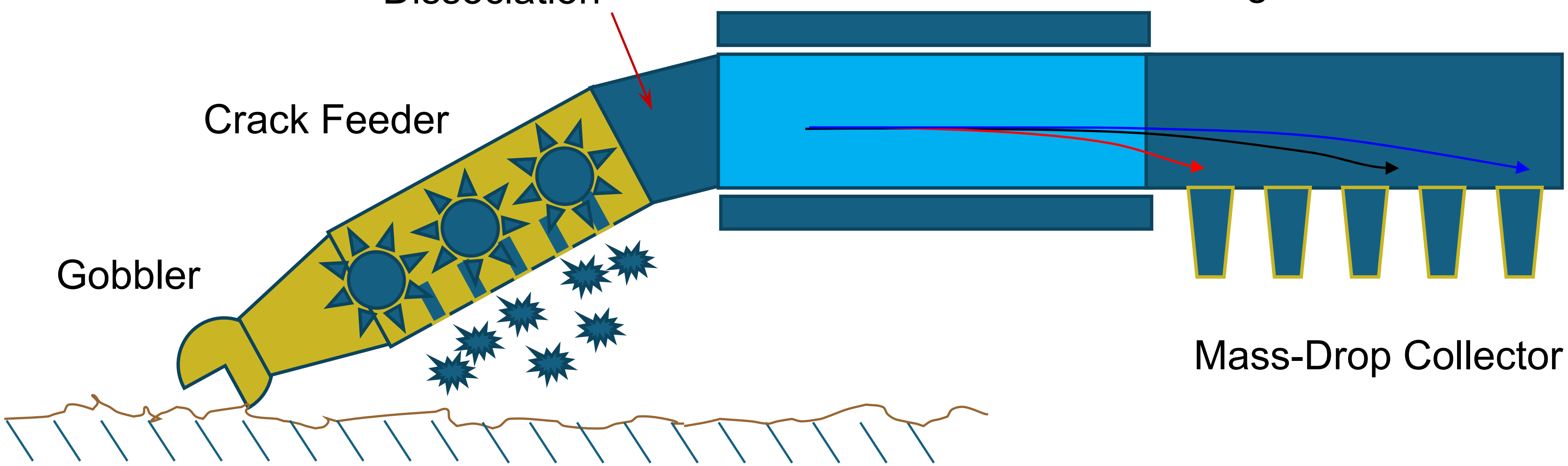


Hypocycloidal field formation is described by the equipotential lines within which any particles ionized or with dipole moment are captured and accelerated along the drift axis by ring field. The ring electrodes are charged with high voltage sequentially with time interval to create ring field.

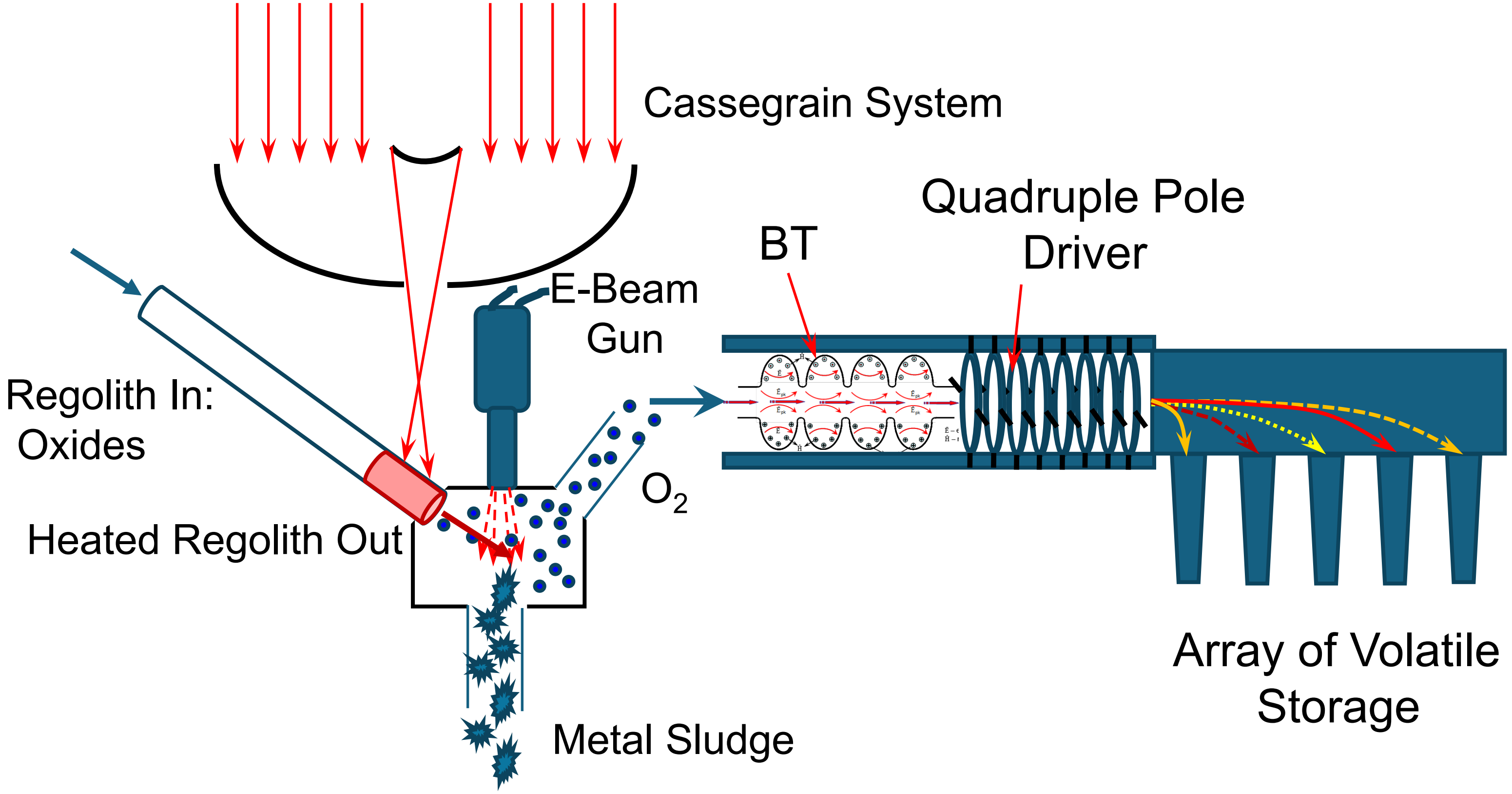


Particle capture by cylindrical harmonic generator in a hypocycloidal mode.

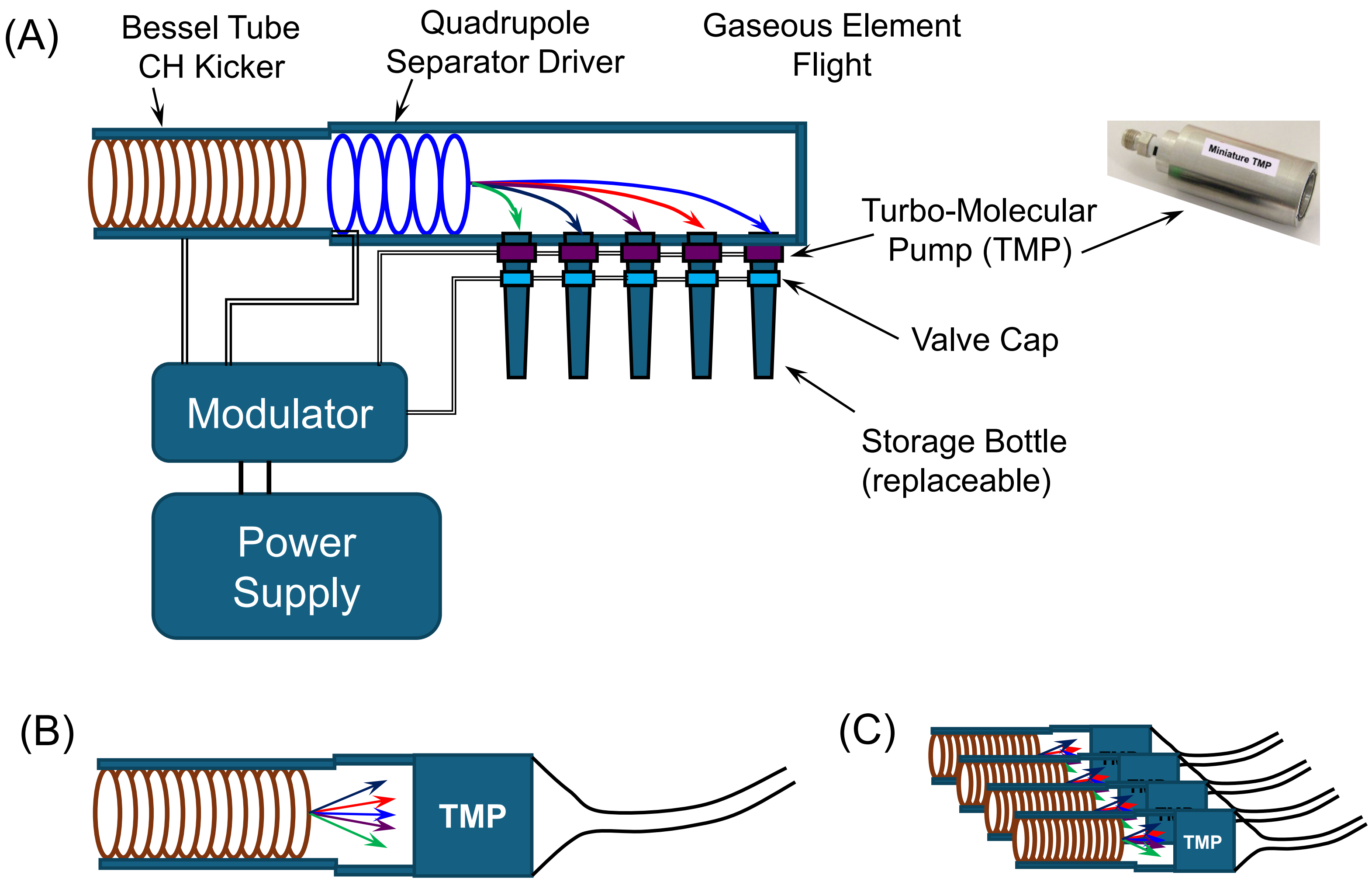
Helium-3 Mining Technology



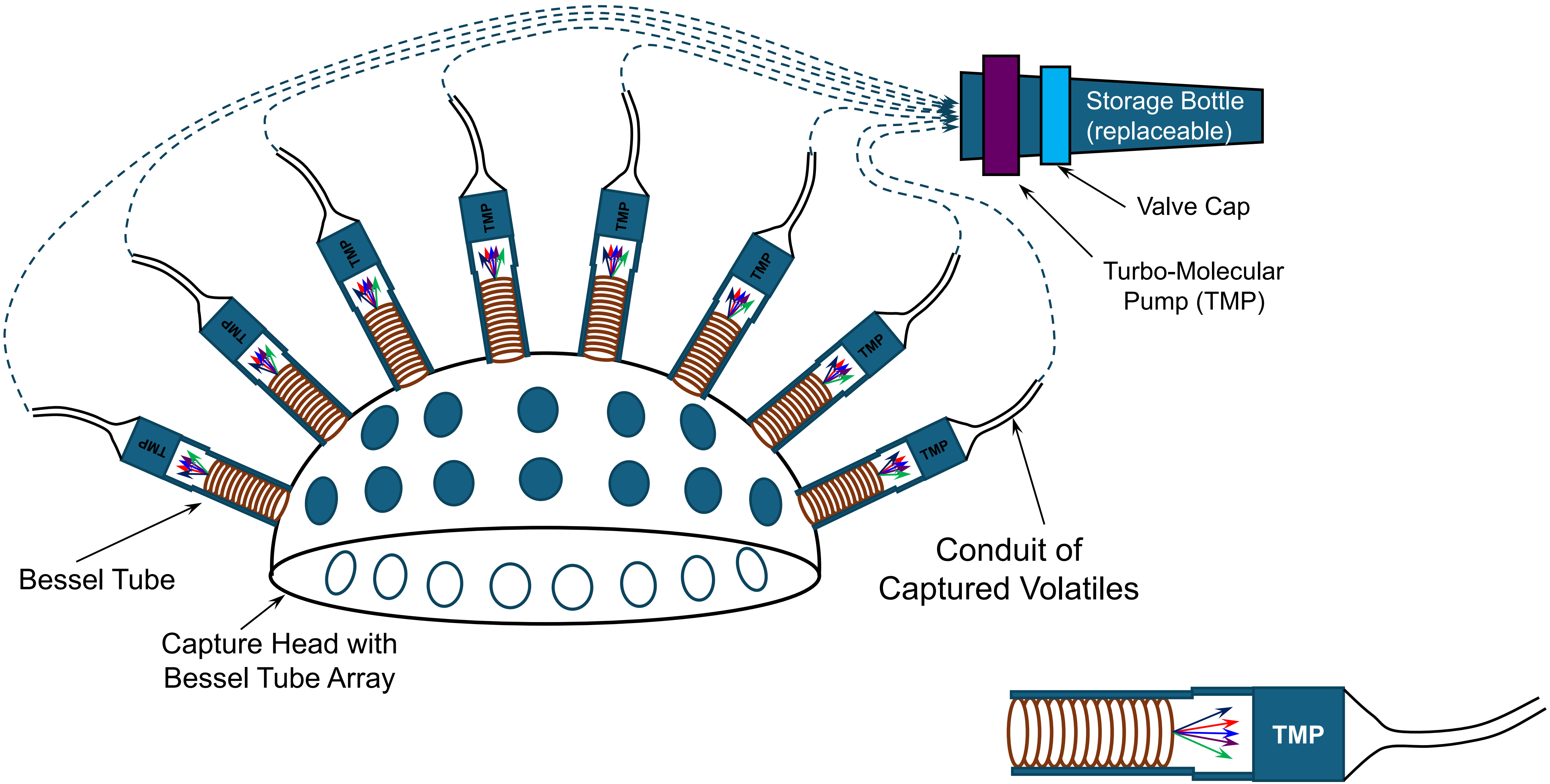
O_2 Separation



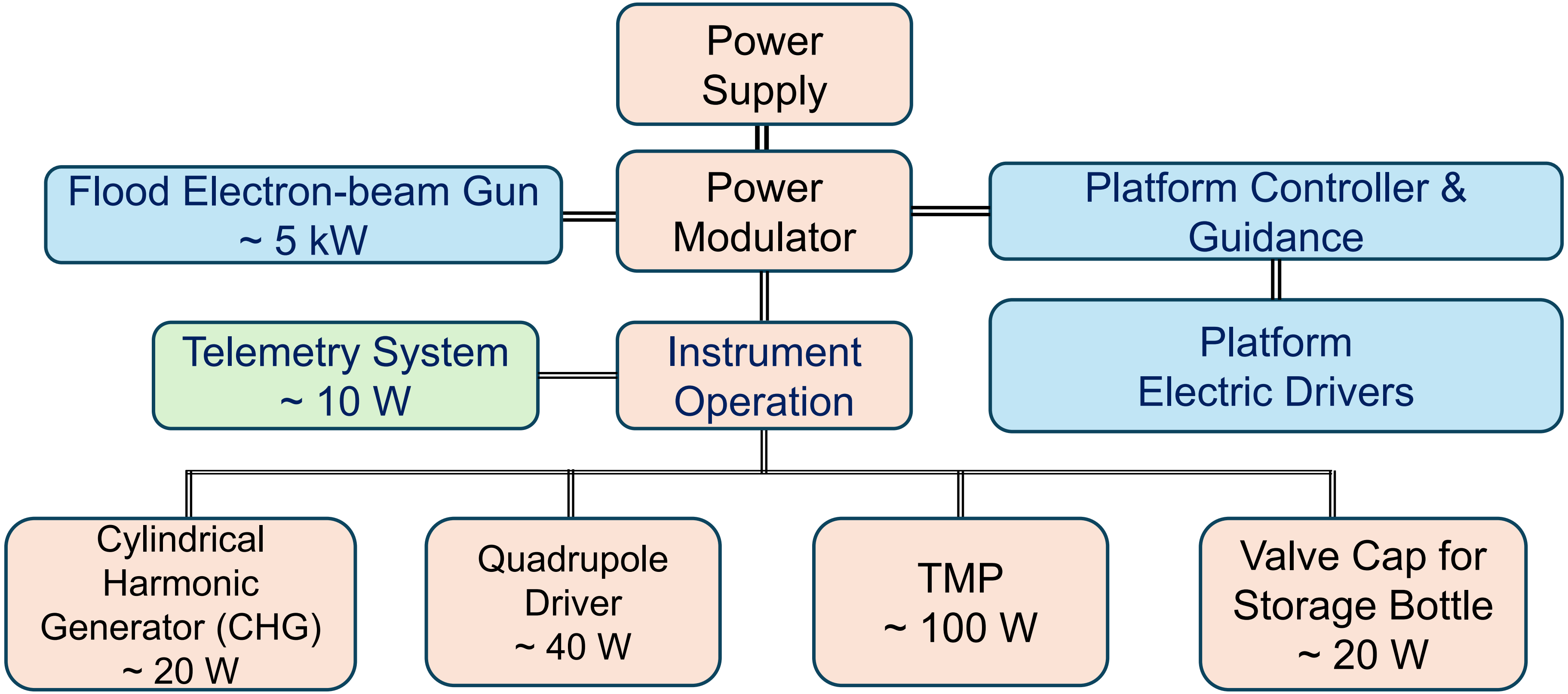
Three Types of Bessel Tube Device



LVC Array for Lunar Volatiles



Power Platform for Volatile Harvesting



- High Power Density -

To date, power usage:

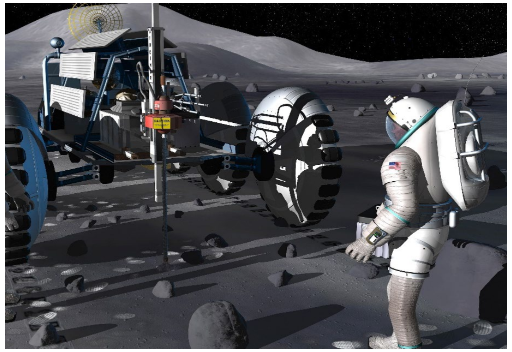
- Lifting by rockets
- Electronic processes – mostly probing and telecommunication

Under Artemis:

- Lifting by rockets
- Electronic processes – probing and telecommunicating
- Mechanical processes – mining, hauling, hauling, storing, fabricating, and constructing
- More power required > 100 kW
- Specific power > 100 W/kg

Power Need for Scientific Missions and Habitats

Sample Drilling (~10kW)



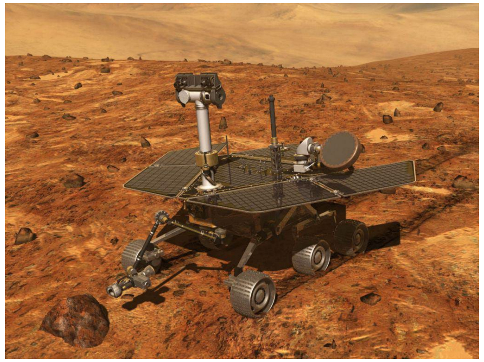
Rover Exploration (~3kW)

Inflatable Habitat (~1kW)

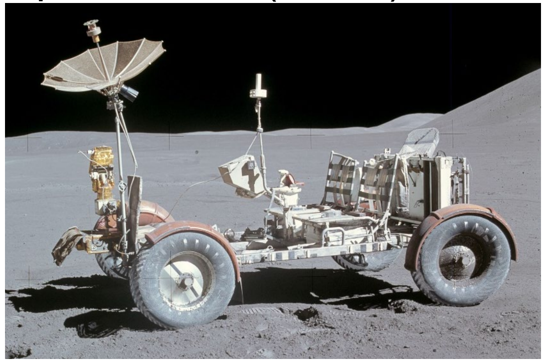
Fixed Habitat (~2kW)

Sojourner (~500W)

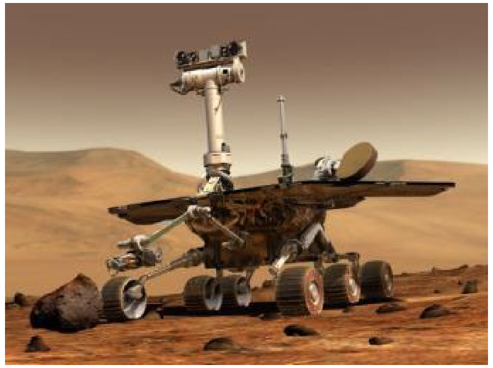
Opportunity (~500W)



Apollo Rover (~1kW)



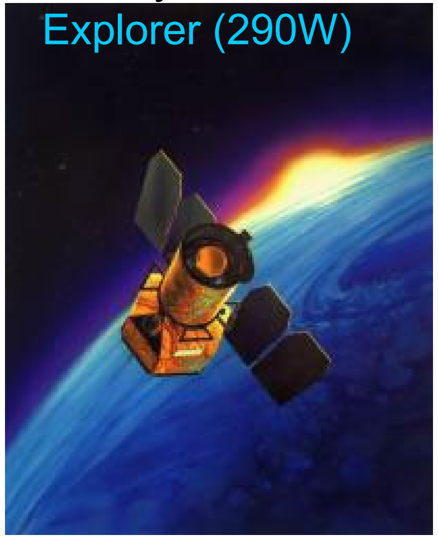
Spirit (~500W)

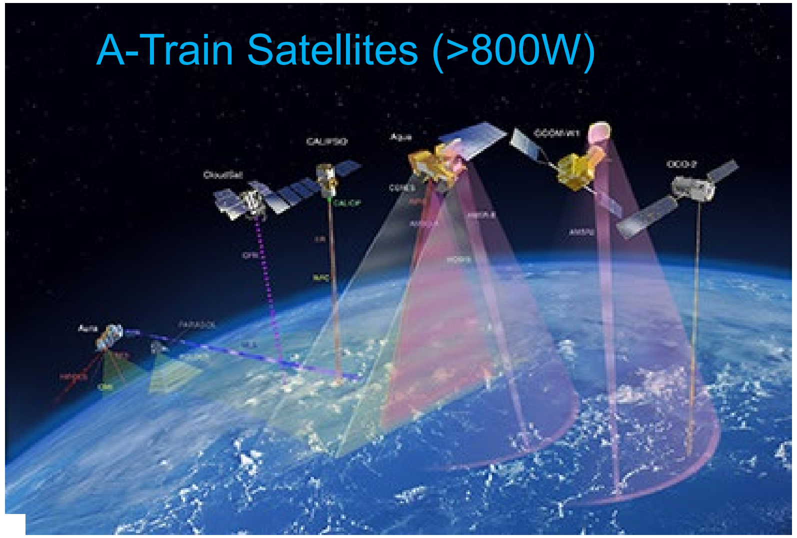


All images credit: NASA

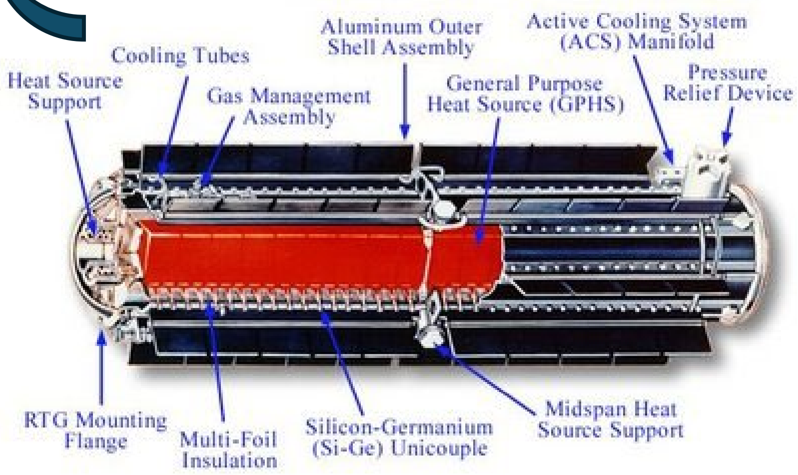
Power for Earth and Space Science

Galaxy Evolution

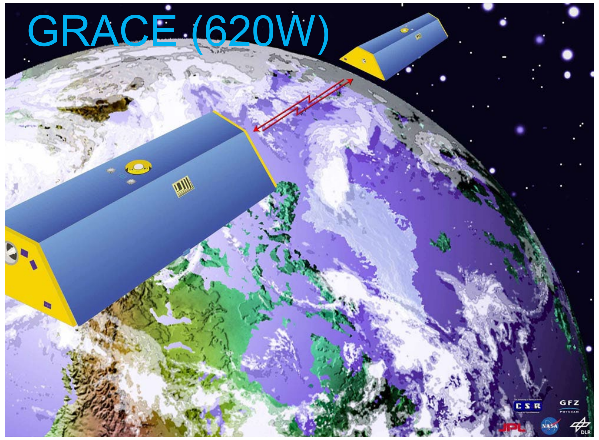




GPHS-RTG 285 W



Radioisotope Thermoelectric Generators (RTG)



All images Credit: NASA

History of Space Radioisotope Thermoelectric Generator (RTG) Applications

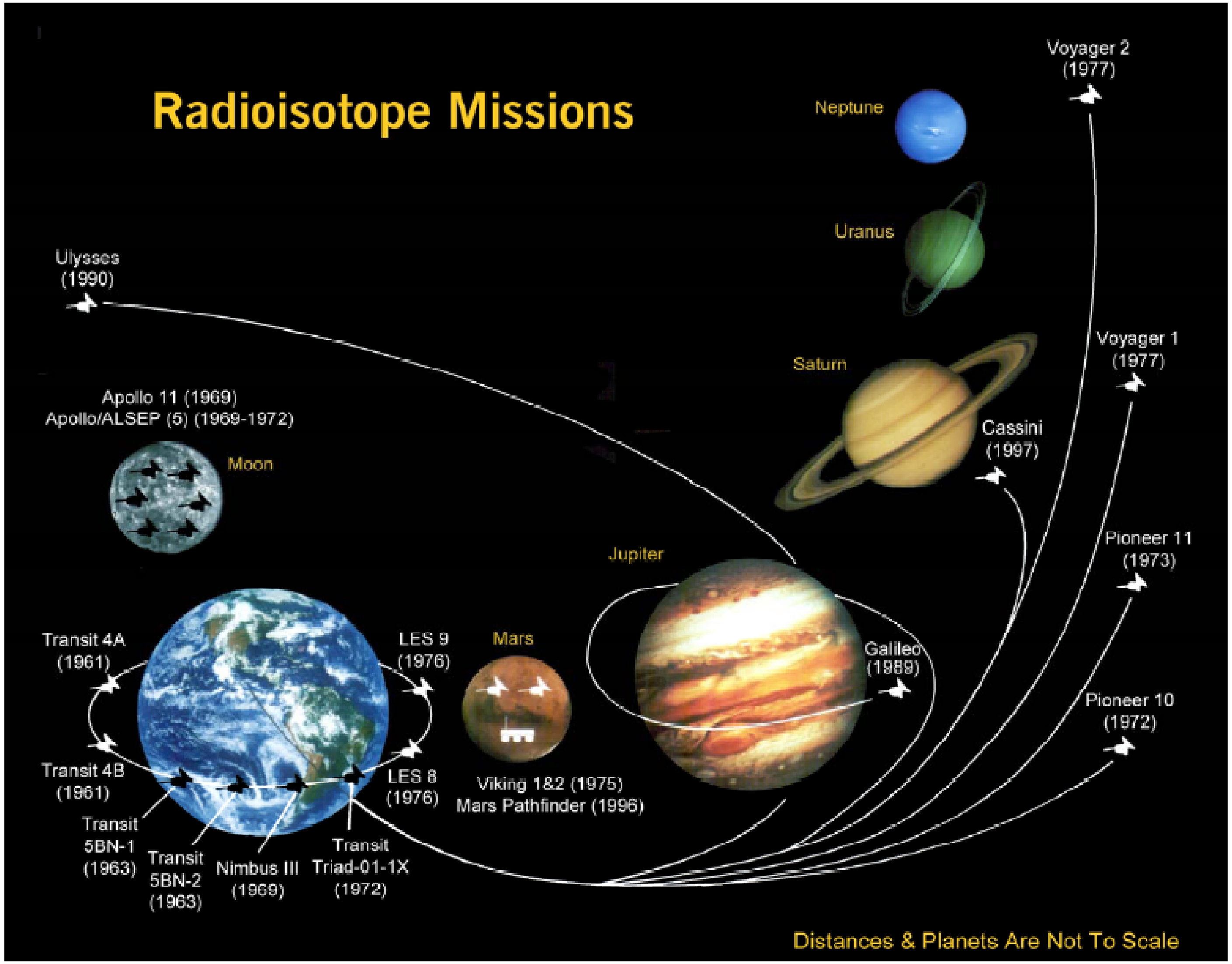


Image & Data Credit: NASA

Name & Model	RTG used	Max Power (watts)	Max Heat Output (Watts)	Radioisotope	Fuel Mass (kg)	Total Mass (kg)
SRG	Prototype phase	~110	~500	Pu238	~1	~27
MMRTG	Prototype phase	~110	~2000	Pu238	~4	26-34
GPHS-RTG	Cassini (3) Galileo (2) Ulysses (1)	300	4400	Pu238	7.8	55.5
MHW-RTG	Voyager 1 (3) Voyager 2 (3)	160	2400	Pu238	~4.5	39
SNAP-19	Viking (2) Pioneer 10 (4) Pioneer 11 (4)	35	525	Pu238	~1	???
SNAP-27	Apollo 12-17 ALSEP (1)	73	1480	Pu238	3.8	20
Beta-M	Soviet unmanned lighthouse	10	230	Sr90	0.26	560

RTG: Radioisotope Thermoelectric Generator

http://en.wikipedia.org/wiki/radioisotope_thermoelectric_generator

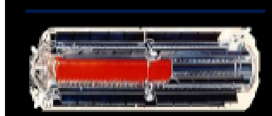
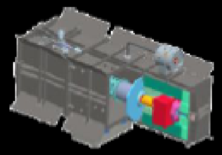
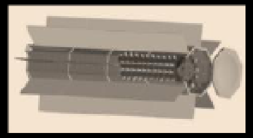
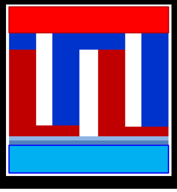
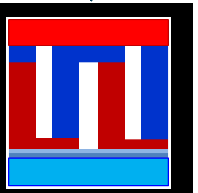
Element	Half-life (years)	Watts/g (thermal)	$/Watt (thermal)
Polonium-210	0.378	141	570
Plutonium-238	86.8	0.55	3000
Cesium-144	0.781	25	15
Strontium-90	28.0	0.93	250
Curium-242	0.445	120	495

Current and Planned

Power Sources for Deep Space Exploration

Images credit to NASA

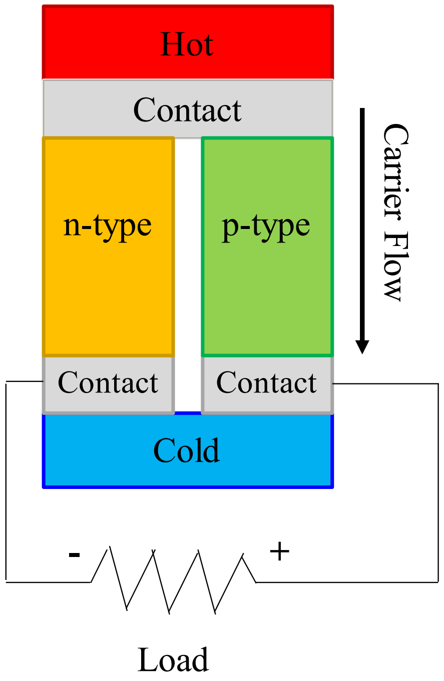
Compared with GPHS-RTG MMRTG

NASA Goal **> 100 W_e/kg** **NTAC > 1 kW/kg**	 GPHS-RTG Past	 MMRTG Present	 ASRG In Development	 ARTG Future	 TPV Future	 **MJ-TE**	 **MJ-TE**
Electric Output, BOM, W_e	285	125	~140-150	~280 to 420	~38-50	**1125~1350**	**600~740**
Heat Input, BOM, W_e	4500	2000	500	3000	250	**4500**	**2000**
RPS System Efficiency, BOM, %	6.3	6.3	~28-30	~9-14	~15-20	**25~30**	**30~37**
Total System Weight, kg	56	44.2	~19-21	~40	~7	**~ 30**	**~ 18**
Specific Power, W_e/kg	5.1	2.8	~7-8	~7-10	~6-7	**37.5 ~ 45**	**33 ~ 41**
Number of GPHS Modules	18	8	2	12	1	**18**	**8**
GPHS Module Weight, kg	25.7	12.9	3.2	19.3	1.6	**< 15**	**< 7**
^{238}Pu Weight, kg	7.6	3.5	0.88	5.3	0.44	**7.6**	**3.5**

GPHS-RTG: general-purpose heat source — radioisotope thermoelectric generator
MMRTG: Multi-Mission Radioisotope Thermoelectric Generator
ASRG: Advanced Stirling Radioisotope Generator
ARTG: Advanced RTG
TPV: Thermo-photovoltaic
MJ-TE: Metallic junction thermoelectrics

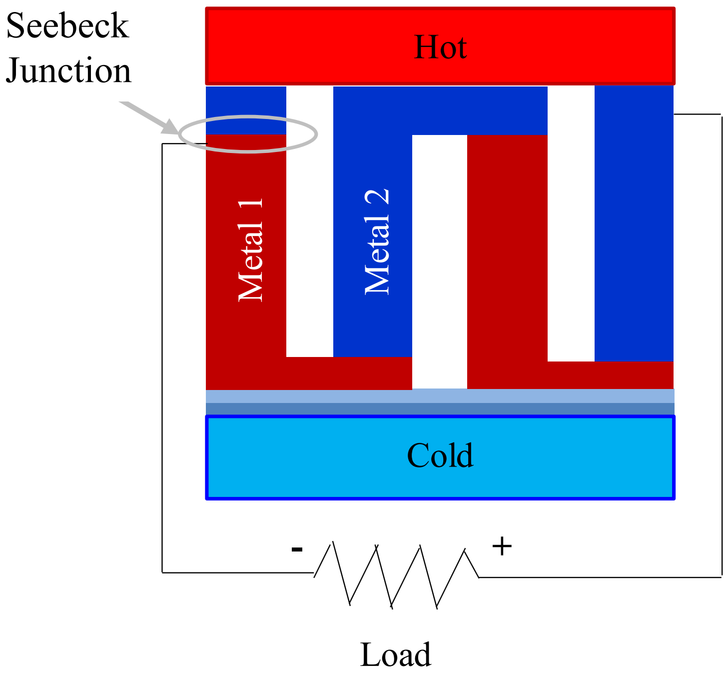
Old vs. *New*

Semiconductor TE



- p-n Junction limits electrons (~1 C/cm^3) from 10^{18}~10^{19} dopant atoms/cm^3
- Requires high σ, low κ
- ZT ~ 0.8 (η ≈ 6 %)

Metallic Junction TE



- Many electrons (~10^3 C/cm^3) from 10^{23} atoms/cm^3
- No need for high σ, low κ
- Higher carrier mobility
- ZT ~ 2 (η ≈ 12 %)

Customary Band (Wave) Energy and Grade

Band	Frequency	Wavelength	Energy	Color Temperature	Grade	
HF	3 ~ 30 MHz	10 ~ 100 m				
VHF	30 ~ 300 MHz	1 ~ 10 m				
UHF	0.3 ~ 3 GHz	0.1 ~ 1 m				
L	1 ~ 2 GHZ	0.15 ~ 0.3 m				
S	2 ~ 4 GHz	0.075 ~ 0.15 m				
C	4 ~ 8 GHz	0.037 ~ 0.075 m				
X	8 ~ 12 GHz	0.025 ~ 0.037 m				
Ku	12 ~ 18 GHz	0.017 ~ 0.025 m			Extremely Low	
K	18 ~ 27 GHz	0.011 ~ 0.017 m				
Ka	26.5 ~ 40 GHz	0.0075 ~ 0.0113 m				
Q	33 ~ 50 GHz	0.006 ~ 0.0091 m				
U	40 ~ 60 GHz	0.0075 ~ 0.005 m				
V	50 ~ 75 GHz	0.004 ~ 0.006 m				
W	75 ~ 110 GHz	0.0027 ~ 0.004 m				
F	90 ~ 140 GHz	0.00214 ~ 0.00333 m				
D	110 ~ 170 GHz	0.00176 ~ 0.00273 m				
Tera (TH)	700 ~ 1700 GHz	42.8 ~ 17.6 μm	0.003 eV ~ 0.007 eV	35 ~ 80 K	Lowest Grade	
Far IR (FIR)	6 ~ 15 THz	50 ~ 20 μm	0.025 eV ~ 0.06 eV	300 ~ 700 K	Low Grade	Current
Mid IR (MIR)	15 ~ 30 THz	20 ~ 10 μm	0.06 eV ~ 0.12 eV	700 ~ 1400 K	Low Grade	Power systems
IR	30 ~ 100 THz	10 ~ 3 μm	0.12 eV ~ 0.3 eV	1400 ~ 3500 K	Low Grade	Anchored
Near IR (NIR)	100 ~ 430 THz	3 ~ 0.7 μm	0.3 eV ~ 1 eV	3500 ~ 11600 K	Low Medium Grade	
Visible (Vis)	430 ~ 1000 THz	0.7 ~ 0.3 μm	1 eV ~ 4 eV	11600 ~ 46420 K	Low Medium Grade	
UV (UV)	750 ~ 1000 THz	0.4 ~ 0.3 μm	3 eV ~ 4 eV	34800 ~ 46420 K	Low Medium Grade	
Deep UV (DUV)	850 ~ 1200 THz	0.35 ~ 0.25 μm	4 eV ~ 6 eV	46420 ~ 69600 K	Medium Grade	
Vacuum UV (VUV)	1.2 ~ 3 PHz	0.25 ~ 0.1 μm	6 eV ~ 12 eV	69600 ~ 139200 K	Medium Grade	
Extreme UV (EUV)	3 ~ 300 PHz	100 ~ 1 nm	12 eV ~ 300 eV	139200 ~ 3480000 K	Medium Grade	
Soft X-ray (SXR)	300 ~ 600 PHz	1 ~ 0.5 nm	300 eV ~ 2 keV	3.48 ~ 23.2 MK	High Grade	
Hard X-ray (HXR)	0.6 ~ 24 EHz	0.5 ~ 0.0125 nm	2 keV ~ 100 keV	23.2 ~ 1160 MK	High Grade	NTAC
Gamma ray (γ-ray)	> 25 EHz	< 0.0125 nm	> 100 keV	> 1.16 BK	Extreme High Grade	

Energy-Releasing Reactions

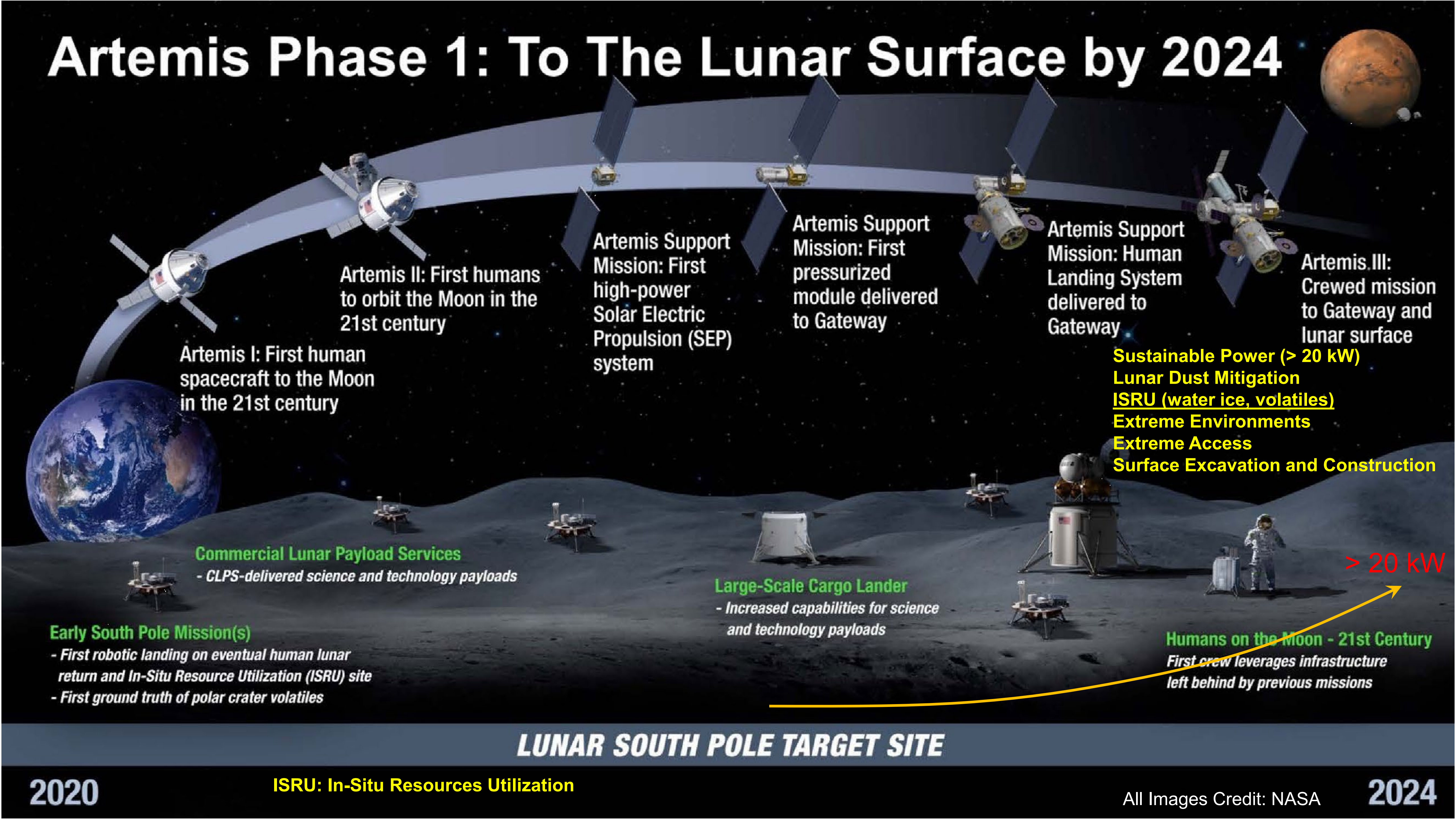
Energy Source	Chemical	Nuclear Fission	Nuclear Fusion	γ-Photoionic
Sample Reaction	$C + O_2 \rightarrow CO_2$	$n + {}^{235}U \rightarrow {}^{143}Ba + {}^{91}Kr + 2n$	${}^{2}H + {}^{3}H \rightarrow {}^{4}He + n$	X-ray, γ-ray, β
Typical Inputs	Coal or oil	UO_2 (3% ^{235}U + 97% ^{238}U)	Deuterium & Tritium	Photons
Typical Reaction Temp (K)	700	1000	10^8	any temp
Energy Released per gram (J/g)	3.3×10^4	2.1×10^9	3.4×10^{11}	1.4×10^8
Harnessable Efficiency (E/mc^2)	3×10^{-8} %	0.002 %	0.4 %	~ 20 %

http://electron6.phys.utk.edu/phys250/modules/module%205/nuclear_energy.htm

Energy Grade	Poorest	High	Highest	Highest
Specific Power	< 10 W/kg	< 25 W/kg	> 100 W/kg	> 1000 W/kg
System α, kg/kW	> 100	> 40	< 10	< 1
Refueling	Frequently	> 10 years	> 10 years	2.5 ~ 30 years
Challenges & Readiness	Pollution	γ & neutron shielding	Plasma fusion (???)	Radioisotopes

NASA Lunar Power- KRUSTY: **A 40 kW_e system with 4-m diameter and 6-m long and Weight > 6,000 kgs**

(KRUSTY: Kilowatt Reactor Using Sterling TechnologY)


Artemis Phase 1: To The Lunar Surface by 2024
Artemis I: First human spacecraft to the Moon in the 21st century
Artemis II: First humans to orbit the Moon in the 21st century
Artemis Support Mission: First high-power Solar Electric Propulsion (SEP) system
Artemis Support Mission: First pressurized module delivered to Gateway
Artemis Support Mission: Human Landing System delivered to Gateway
Artemis III: Crewed mission to Gateway and lunar surface
Sustainable Power (> 20 kW)
Lunar Dust Mitigation
ISRU (water ice, volatiles)
Extreme Environments
Extreme Access
Surface Excavation and Construction
> 20 kW
Commercial Lunar Payload Services
- CLPS-delivered science and technology payloads
Large-Scale Cargo Lander
- Increased capabilities for science and technology payloads
Early South Pole Mission(s)
- First robotic landing on eventual human lunar return and In-Situ Resource Utilization (ISRU) site
- First ground truth of polar crater volatiles
Humans on the Moon - 21st Century
First crew leverages infrastructure left behind by previous missions
LUNAR SOUTH POLE TARGET SITE
2020
ISRU: In-Situ Resources Utilization
All Images Credit: NASA
2024

Power Technology Roadmap for Future Lunar Missions

Alignment of Power Sources with Lunar Surface Systems Needs

Location:* *Polar (near continuous light)

NASA Glenn Research Center| Jeremiah McNatt and Fred Elliott | November 04, 2019

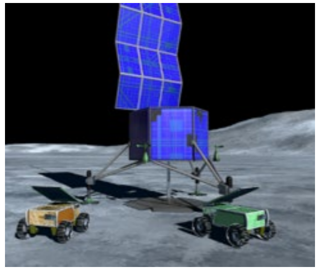
	Application / Capability	Power Level	Power Source Suitability and Readiness: Radioisotope Power	Fission Power	Photovoltaics	Batteries	Primary Fuel Cells	Regen Fuel Cells
Uncrewed	Lander, Small Robotic, NET 2020	< 500 W						
		500 W – 1 kW						
	Lander, Mid-size Robotic, NET 2022	1 – 3 kW						
	Lander, Large Robotic, NET 2026	3 – 7 kW						
	Mobile, Small Robotic Rover, NET 2022	< 500 W	NextGen RPS			Lunar night survival		
		500 W – 1 kW	Dynamic RPS			Lunar night survival		
	Mobile, Large Robotic Rover, NET 2026	1 – 3 kW		Recharge Only		Lunar night survival		
	ISRU, NET 2027	3 – 7 kW				Lunar night survival		
		7 – 20 kW	NTAC					
Crewed	Lander, Advanced Exploration, NET 2026	3 – 7 kW						
	Rover (unpressurized), NET 2023	1 – 3 kW						
	Rover (small pressurized)	3 – 5 kW		Recharge Only		Lunar night survival	ISRU Reactants	Station Recharge
	Rover (pressurized), NET 2026	7 – 20 kW	NTAC	Recharge Only			ISRU Reactants	Station Recharge
	Ascent Stage, NET 2024	3 – 7 kW						
	Habitat, NET 2031	4 – 10 kW	NTAC					

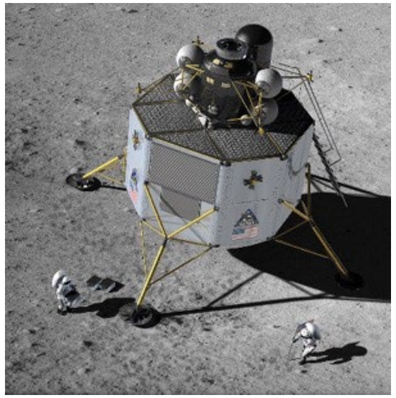
RPS: Radioisotope Power Systems
NTAC: Nuclear Thermionic Avalanche Cell

Color key: SOA adaptable | Funded Development | Dev started – more needed | Development needed | Not suitable/practical

Artemis Mission Architecture

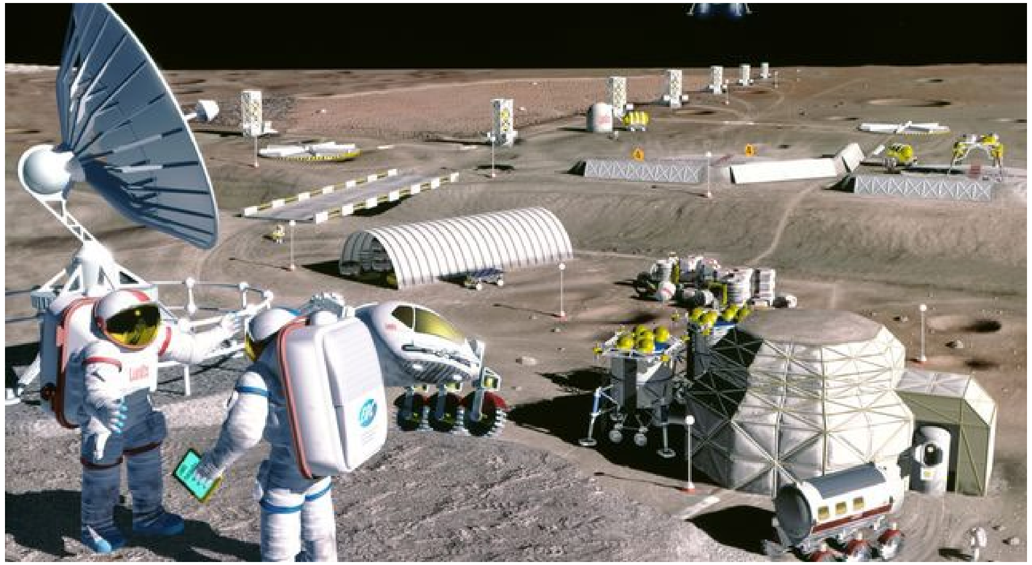
2024





2030

2035



NASA Glenn Research Center| Jeremiah McNatt and Fred Elliott | November 04, 2019

All Images Credit: NASA

Scientific Landers

~ 1 kW

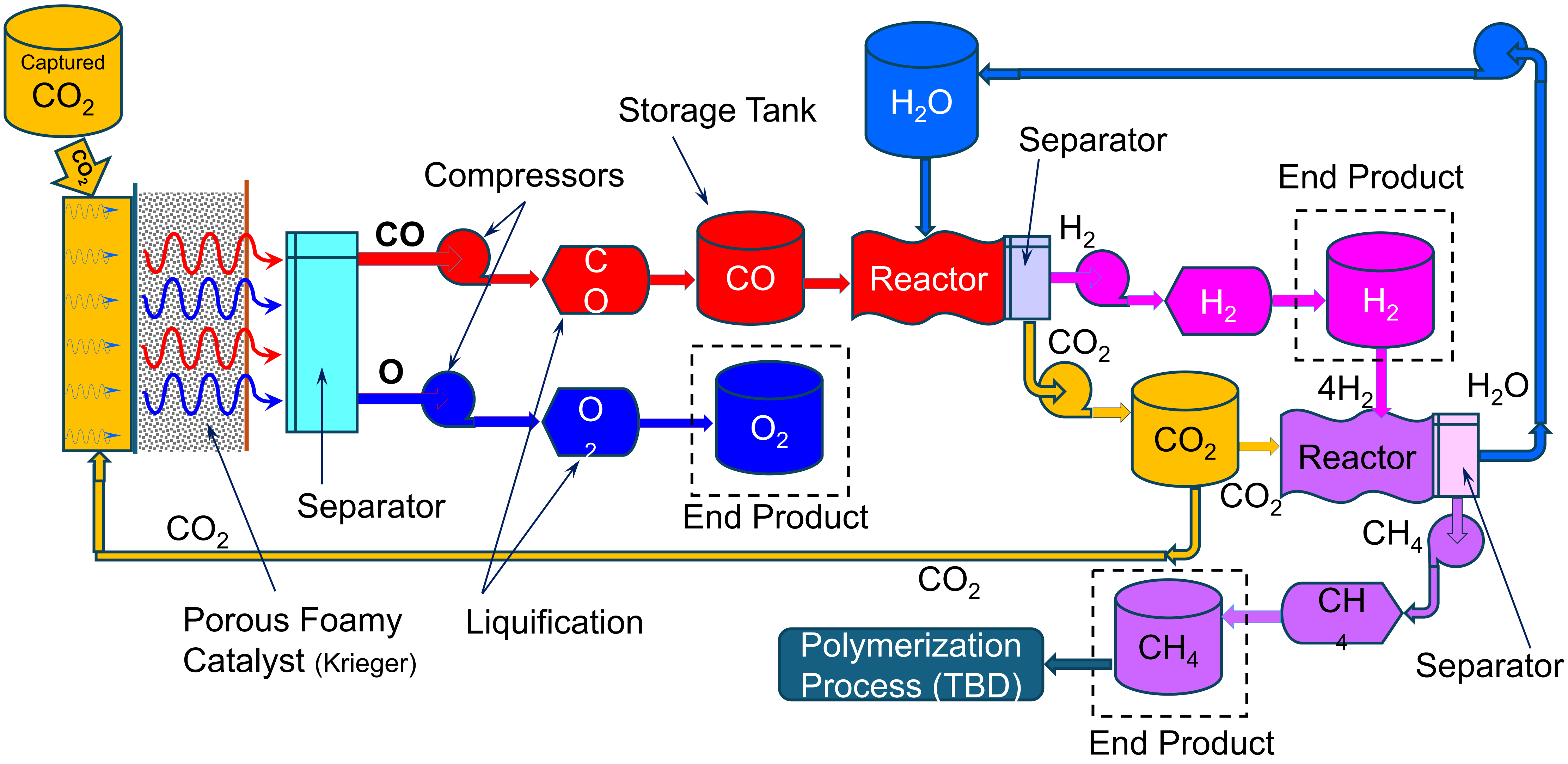
Rovers, Crewed Missions from Lunar Gateway

~ 20 kW

Lunar Base (habitat, charging station, ISRU plant)

> 100 kW

Propellant Production Process



Krieger, Kim, "Breaking carbon dioxide faster, cheaper, and more efficiently", Proceedings of the National Academy of Sciences (2019). DOI:10.1073/pnas.1915319116
Sang H. Choi and Robert W. Moses, "Integrated Dissociation Processing of Carbon Dioxide", NASA Case No. LAR-19916-1, e-NTR #: 1600455401, September 18, 2020.

CO_2 Mining and Processing Power

$2CO_2 + 4h\nu \rightarrow 2CO + O_2$ $E = -4h\nu = -1.35$ eV = - 130.26 kJ/mol

- Breakdown rate of CO_2 into CO + O: **1 kg/s of CO_2**
- **1 eV = 96.49 kJ/mol**
- **1 kg of CO_2 = 22.7 moles**
- E = - 1.35 eV = - 130.26 kJ/mol = - 2957 kJ/kg

Power required: P_{CO2} = 2957 kJ/s ≈ 3 MW for breaking down 1 kg/s of CO_2

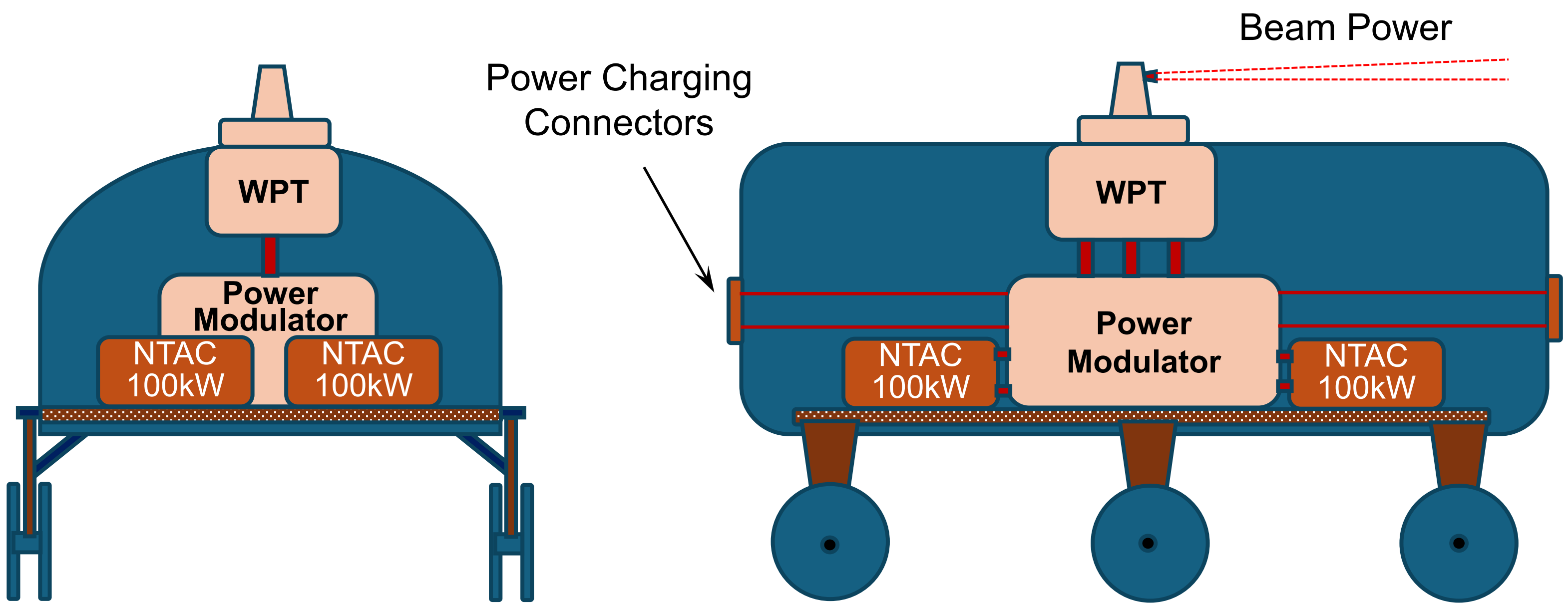
Dissociation Rate	E, kJ	Power, kW	System Power, kW	NTAC Power Source, MW	NTAC Dimension
1 g/s	- 2.957 kJ	2.96 kW	10 kW	3.844 MW	D: 1.2m, H: 1.5m W: 3.5 tons System Alpha: 0.908
100 g/s	- 295.7 kJ	296 kW	10 kW	3.844 MW	
300 g/s	- 887.1 kJ	888 kW	50 kW	3.844 MW	
500 g/s	- 1478.5 kJ	1.480 MW	200 kW	3.844 MW	
1 kg/s	- 2957 kJ	2.957 MW	200 kW	3.844 MW	

Solar Cell vs. NTAC

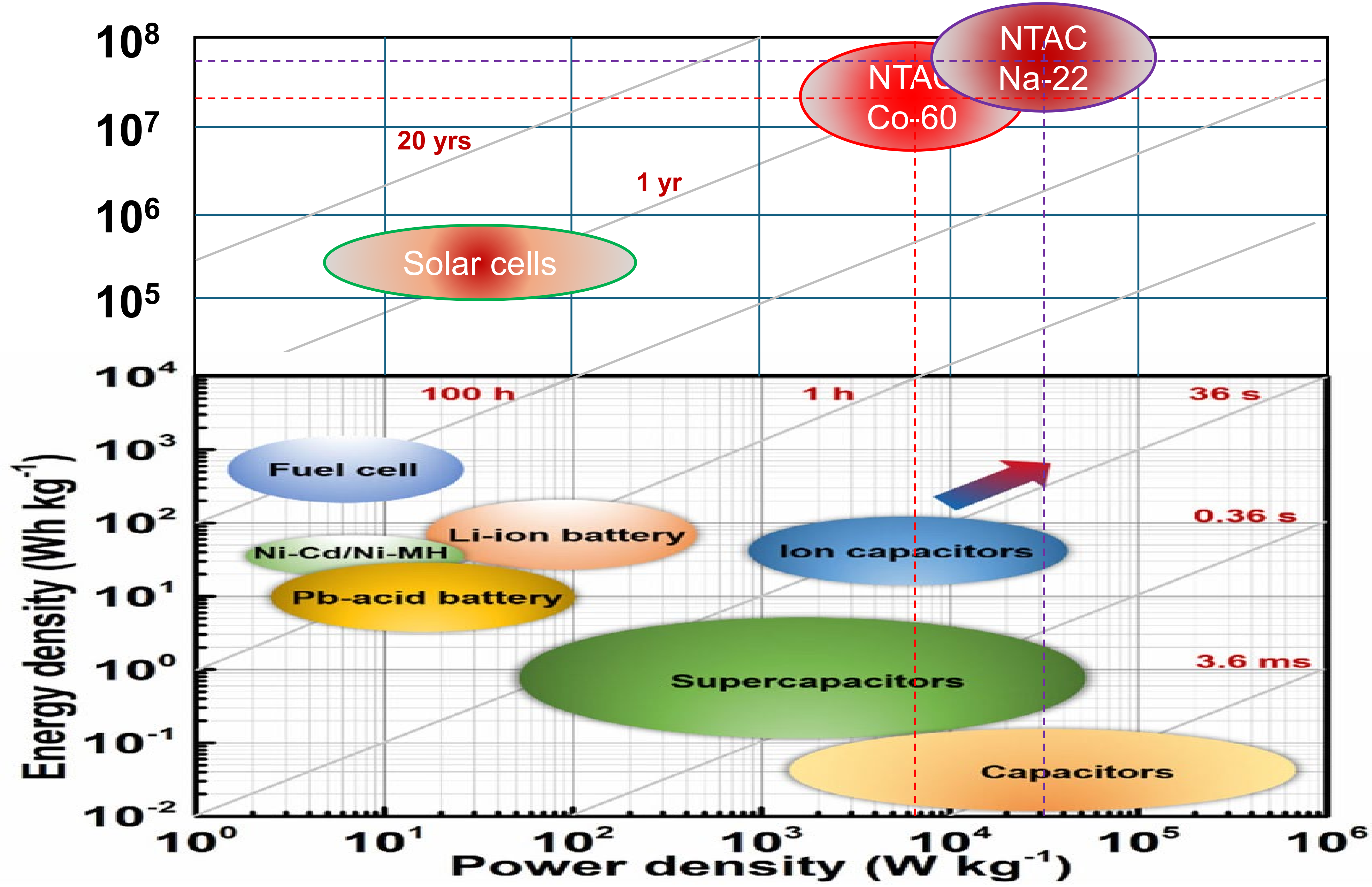
Device	ETS-VIII Solar Array	NTAC 7.5 kW ½ Life	NTAC 15 kW ½ Life
Type	Rigid type	Solid – no moving part	Solid – no moving part
Size, m	L-18.8m, W-2.5m	D-0.282m, H-0.4m	D-0.307m, H-0.4m
Mass, kg	114.2kg/wing; Total 228.4 kg	126 kg	148 kg
Electrical Power, kW	P_3 = 7.5kW → P_{10} = 6.7kW	P_{BoL}= 23 kW → $P_{½}$= 11.5 kW	P_{BoL}= 47 kW → $P_{½}$= 23.5 kW
Power Density, kW/kg	**0.0328 → 0.0293**	**0.18 → 0.09**	**0.3 → 0.16**
System α, kg/kW	**30 → 34**	**5.5 → 11**	**3 → 6**
Cell Structure/Materials	Mono Si	Co-60/ $Cu\text{-}Al_2O_3\text{-}La$	Co-60/ $Cu\text{-}Al_2O_3\text{-}La$
Circuits	48 for 524x88 array	7 into a modulation circuit	7 into a modulation circuit
Configuration	Flat panel	Cylindrical	Cylindrical
Sub-Structure	Al-honeycomb rigid panel	With Shielding & MJ-TE structure	With Shielding & MJ-TE structure

NTAC Power Rover

NTAC	Diameter	Height	Unit Weight	Units Onboard	Total Weight	Total Power	System α
100 kW_e	0.484 m	0.23 m	213 kg	4	852 kg	400 kW_e	1.87
200 kW_e	0.584 m	0.24 m	319 kg	4	1276 kg	800 kW_e	1.30



Comparison of Power Devices

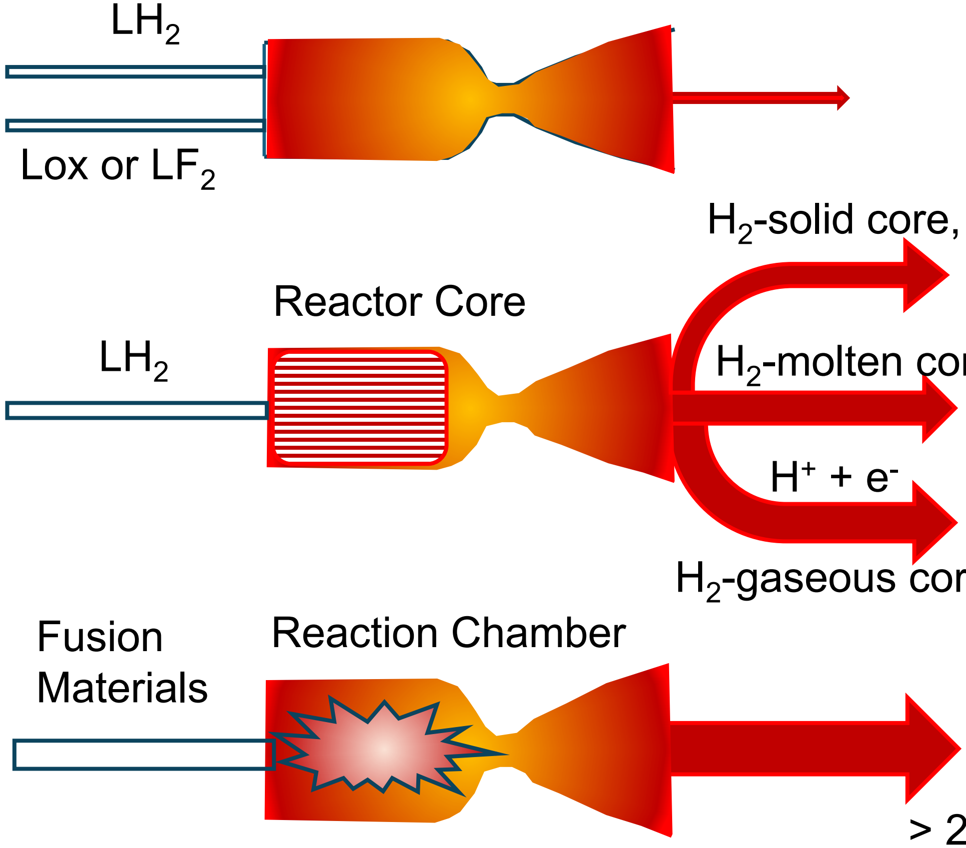


Logistics

- Rocket Technology -

Chemical propulsion:	Support the Cis-lunar activities
MPD propulsion:	Potential long-haul transportation
Nuclear fission propulsion:	Long-haul transportation
Nuclear fusion propulsion:	Long-haul travel (out of planet)

Comparison of Rocket Propulsion System Characteristics



Energy Source	Theoretical Specific Impulse	Mass Ratio*, Earth Escape
Chemical Reaction	440 s	15
Nuclear Fission Reaction (H_2-solid core, 2800 K)	980 s	3.2
Nuclear Fission Reaction (H_2-molten core, 5250 K)	2600 s	1.5
Nuclear Fission Reaction (H_2-gaseous core, 10000 K)	6700 s	1.2
Nuclear Fusion Annihilation	1.3~3 Ms	

*Ratio of take-off to final mass

Propulsion Methods

Propulsion Technology	Exhaust Velocity (m/s)	Thrust (N)	Duration	ΔV (km/s)	TRL
Solid Propellant Rocket	< 2,500	$< 10^7$	minutes	7	9
Liquid Propellant Rocket	< 4,400	$< 10^7$	minutes	9	9
MPD Thruster	20,000 ~ 100,000	100	weeks	?	6
VASIMR	10,000 ~ 300,000	40 ~ 1200	days ~ months	> 100	5
Solar Thermal Rocket	7,000 ~ 12,000	1 ~ 100	weeks	> 20	4
Nuclear Thermal Rocket*	9,000	10^7	minutes	> 20	6
Nuclear Pulse Propulsion (Orion Project)	20,000 ~ 100,000	$10^9 \sim 10^{12}$	days	30 ~ 60	3
Nuclear Pulse Propulsion (Daedalus Project)	20,000 ~ 1,000,000	$10^9 \sim 10^{12}$	years	15,000	2
Fusion Rocket	100,000 ~ 10,000,000	$10^{10} \sim 10^{13}$	?	?	2
Antimatter Rocket	10,000,000 ~ 100,000,000	?	?	?	2

*currently in development

Source: http://en.wikipedia.org/wiki/Spacecraft_propulsion

Concluding Remarks

- Bullet type micro-spectrometer and deployment gun were designed for space applications.
- Applications of micro-spectrometer bullets include mineral mapping on the Moon, Mars, and asteroids, especially hillsides and deepened bottom floor of craters.
- Lunar Volatiles Collector (LVC) based on Bessel Tube is in an infant stage.
- Portable high-density power technology of at least > 100 W/kg is essential for space, Lunar, and Planetary Applications.
- Current propulsion systems are only sufficient for cis-lunar activities. New propulsion systems with high Isp and high thrust are required.